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Technical Report No. 6

DETERMINATION of BEACH CONDITIONS by means of AERIAL PHOTOGRAPHIC INTERPRETATION

Volume II

VARIATION and STABILITY of BEACH FEATURES

(including an Appendix on Wave Tank Tests)

Cornell University
Office of Naval Research

TECHNICAL REPORT NUMBER 6

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by means of

AERIAL PHOTOGRAPHIC INTERPRETATION

VOLUME II

VARIATION AND STABILITY

of

BEACH FEATURES

(including an Appendix on Wave Tank Tests)

In connection with
a contract between:

Amphibious Branch, Office of Naval Research — School of Civil Engineering, Cornell University

U. S. Naval Photographic Interpretation Center, Monitor

Executed by the

Cornell Center for Integrated Aerial Photographic Studies

Beach Accessibility and Trafficability

Project No. NR 257 001

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by

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with

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KEY TO TECHNICAL REPORT NUMBER 6

Technical Report Number 6 is divided into five Volumes. The titles of these Volumes are as follows:

Volume I	-	Relations Between Beach Features and Beach Conditions.
Volume II	-	Variation and Stability of Beach Features (including an Appendix on Wave Tank Tests).
Volume III	-	Photographic Gray Tones as an Indication of the Size of Beach Materials.
Volume IV	-	The Cone Penetrometer as an Index of Beach Supporting Capacity (Moisture, Density and Grain-Size Relations).
Volume V	-	A Method for Estimating Beach Trafficability from Aerial Photographs.

ACKNOWLEDGMENTS

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Credit also belongs to Miss Barbara Freeman and Mrs. Shola Stern for completion of the tedious task of report preparation and assembly.

CONTENTS

CAUTIONARY NOTE

It is the ultimate objective of this research program to investigate and report upon a method for estimating beach trafficability by means of aerial photographic analysis. Trafficability is a tenuous term. For the purpose of this study, it has been considered to be related to:

1. Slope of beach
2. Bearing capacity of beach

Outside factors such as vehicle types, loads and tire pressures; driver abilities and surf conditions; and multiple pass effects were not considered.*

Two things must be emphasized. First, the trafficability diagram appearing as Figure 2 of Volume I and mentioned thereafter, relates slope and penetration values and assigns any given beach to one of five classes. THIS DIAGRAM IS INDICATIVE ONLY AND SHOULD NOT BE USED WITHOUT VERIFICATION OR MODIFICATION IN THE LIGHT OF CURRENT OPERATIONAL TECHNIQUES.

Secondly, the index of beach sand bearing capacity chosen by the authors for use in this investigation was constant weight penetration. The authors believe this to be a reasonable and acceptable index.** However, THE SIGNIFICANCE OF THE INDEX WITH RESPECT TO ACTUAL OPERATIONS MUST BE EVALUATED BY USING AGENCIES.

These statements emphasize the necessity for studies which will correlate penetrations with operating conditions. Only by this means can the research results discussed in Technical Report #6 by utilized to their fullest extent.

* See Progress Report #1, "Relations Between Beach Features Visible on Airphotos and Beach Trafficability".
** See Volume IV (Key).

LIST OF ABBREVIATIONS

AFS	-	Average foreshore slope (See Appendix A)
APR	-	Average penetration reading
Bs	-	Backshore
d	-	Divergence (See Figure 10)
D_{50}	-	Median grain-size (See Figure 10 and Appendix A)
Dec D_{50}	-	Decimal median grain-size (See Figure 10)
DFs	-	Drying foreshore
Fs	-	Foreshore
Fs MSLW	-	Foreshore mean-sea-level width (See Figure 9b and Appendix A)
PR	-	Penetration readings
WFs	-	Wetted foreshore

SECTION I

INTRODUCTION

SCOPE OF VOLUME

This Volume is concerned with the factual aspects of one subdivision of a current research project conducted for the Amphibious Branch, Office of Naval Research. It describes the results obtained from an analysis of Routine Beach Observations* from a number of beaches on the East and West coasts of the United States.

A series of conclusions appears as SECTION IV. These conclusions are based, for the most part, on the data, analyses, and discussions included herein. Consequently, they represent the specific conclusions of the report -- not conclusions of the complete research program.

Final conclusions of the complete research program will be limited in nature. Only those factual aspects that are pertinent to the ultimate objectives of the program will appear. These will be published in Volume V.

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* Also included in this report is a digest of the results obtained from a series of controlled wave tank tests. This digest appears in Appendix B.

ULTIMATE OBJECTIVES OF

COMPLETE RESEARCH PROGRAM

The ultimate objectives of the complete research program are:

1. The presentation of relations between physical features (visible on aerial photographs) that are associated with beaches, and the trafficability of beaches.*

2. The formulation, based upon such relations, of a method for estimating the trafficability conditions of beaches from aerial photographs.

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* See CAUTIONARY NOTE

SPECIFIC OBJECTIVE OF VOLUME

The primary objective of this volume, as mentioned under SCOPE, is the presentation of factual information gained from routine observations taken on a number of beaches on the east and west coasts of the United States. The information is presented in two sections, each concerned with a separate subject:

1. Variation and stability of beach conditions.
2. Validity of relations (reported in Volume I) between beach features and beach conditions.

The presentation of factual information concerning each of these subjects can be considered the specific objective of the volume.

A secondary objective is the presentation of a summary of controlled wave tank tests. This summary appears in Appendix C.

PROBLEMS OF RESEARCH

There are numerous features associated with beaches that may have some relation to trafficability and that can also be seen on aerial photographs. These are:

1. Details of beach profile (width, slope, cusps, scarps)
2. Wave and surf features (length, frequency, shape, direction, refraction, breaker patterns)
3. Gray tones (beach sands, moisture holding capacity, turbidity stains, depth differences)
4. Environmental features (offshore and onshore protection, river mouths, sources of supply, indications of littoral current flow)
5. Miscellaneous features (current ripples, bars)

These features, as well as trafficability itself, reflect the interaction of numerous variables. The variables are:

1. First order variables (independent)
   - a. Location and variations in winds
   - b. Environment
     - (1) Protective underwater features
     - (2) Protective surface features
     - (3) River and tidal mouths
     - (4) Littoral currents
     - (5) Geological sources and types of materials that contribute to beach

(6) General offshore slope

c. Tides

2. Second order variables (dependent upon first order)

   a. Wave characteristics and variations

3. Third order variables (dependent upon first and second order)

   a. Variations in local offshore slopes, bars and local material supplies.

None of these variables can be controlled by any normal means. Few can be evaluated easily by instrumental devices. Consequently, it is difficult to relate specific beach features to the variable or combination of variables that produce them. To satisfy the practical requirements of the project, it was decided to subordinate the relations between beach features and their causative variables and to emphasize direct relations between features and trafficability conditions.

SCHEME OF COMPLETE RESEARCH PROGRAM (CURRENT)

The current program was subdivided into various separate activities. This was done in an attempt to circumvent some of the difficulties previously discussed by varying the direction of attack.

The subdivisions established were as follows:*

1. ROUTINE BEACH OBSERVATIONS (SUBJECT OF THIS REPORT).

   THE COLLECTION OF ROUTINE OBSERVATIONS AT PERMANENT BEACH STATIONS FOR A REASONABLE PERIOD OF TIME. THIS PHASE WAS DESIGNED TO GIVE INFORMATION CONCERNING THE CHANGES OF BEACH FEATURES AND CONDITIONS ON BEACHES OF VARIOUS TYPES <u>OVER A PERIOD OF TIME</u>. THIS PHASE, SINCE IT WAS CONCERNED WITH TIME, WAS EXPECTED TO THROW SOME LIGHT ON THE RELATIVE IMPORTANCE OF CAUSATIVE VARIABLES SUCH AS WAVES, MATERIAL CHARACTERISTICS, ETC..

2. Empirical Beach Survey

   The collection and analysis of information concerning the physical and penetrometer profiles and the sand characteristics of

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* For titles and subject matter of various volumes, see key following title page of this volume.

various beaches picked at random. This phase, since it neglected time, waves and environment, was designed to provide relations between <ins>visible features and trafficability conditions regardless of any causative variable except beach materials</ins>.

3. Penetration - Compaction Studies

   A small laboratory study of the relations between penetrometer readings, compaction and grain characteristics.

4. WAVE TANK INVESTIGATION (INCLUDED AS APPENDIX C)

   A SMALL INVESTIGATION OF GENERAL RELATIONS BETWEEN SLOPE, SLOPE VARIATIONS AND RELATIVE STABILITY AS AFFECTED BY CHANGES IN THE CHARACTERISTICS OF WAVES ACTING UPON MATERIALS OF DIFFERENT GRAIN-SIZE.

5. Gray Tone Studies

   A densitometric study of gray-tones on the beach as indicators of predominant sizes of beach materials and their relative firmness.

Each of these subdivisions will be treated in subsequent reports.

SECTION II

VARIATION and STABILITY

of

BEACH CONDITIONS

GENERAL

It is the purpose of this section to supply partial, general answers to the following questions:

1. Are beach conditions (slopes, widths, median grain-sizes, penetrations) characterized mainly by fluctuations with respect to time or are they essentially static?

2. If fluctuations are the rule rather than the exception, what is their nature and how do they occur:

   a. Is there, for each beach, a "normal" daily fluctuation of predominant character?

   b. Are occasional changes, beyond the "normal" daily fluctuation, to be expected?

   c. What is the extent of normal daily fluctuation?

   d. Can beaches be classified according to their normal ranges of fluctuation?

   e. Do occasional changes occur with great rapidity or do they cover a reasonable period of time?

   f. Do some beach features show greater or less stability than others?

   g. Are normal and occasional changes significant with respect to "trafficability" conditions and/or their estimates?

3. Are some types of beaches more stable than others?

4. Is there any apparent relation between beach changes and possible causative variables such as wave variations, currents, etc..?

As explained in the introduction, it is impossible in a study of this limited scope and support to obtain any detailed conclusions regarding the inter-relationships of independent and dependent causative variables and their separate or combined results. Rather, it is necessary to confine the discussion to data of an empirical nature and attempt to derive as much practical benefit as possible from it.

Although, only partial general answers to the above questions may be expected from an investigation of this limited nature, such partial answers are of considerable importance. During the past ten years, physical data concerning many beaches has been gathered by various beach-survey teams. In most cases, the data was gathered at a single time. Consequently, it is important to determine whether the data can be considered applicable to the single time only or whether it can be extended intelligently over wider periods.

Information concerning stability is also of great importance in determining a usable method for evaluating beach conditions from aerial photographs. Since each aerial photographic set provides information on a single time only, it is desirable to get some idea concerning the total number of photographic sets, together with their spacing in time, that is required for an intelligent evaluation of beach conditions.

DISCUSSION OF QUESTION ONE

Are beach conditions characterized mainly by fluctuations or are they essentially static?

An examination of Figures 5 to 17, Appendix A, will show that on every beach for which observations were received, slopes, widths, grain-sizes and penetrations fluctuated daily, both individually and in variable combinations. On some beaches (16, 17B and 17A for example), static conditions were approached in some respects. However, even on these beaches, the daily changes outnumbered the daily constancies.

The answer to question 1 is clear. Generally, beach conditions are characterized by fluctuations with respect to time, approaching static conditions only for comparatively short periods.*

* Beaches having the characteristics of 16, 17B and 17A (wide, gentle with fine median grain sizes) may be essentially static for longer periods than other beaches.

DISCUSSION OF QUESTIONS 2a and 2b

Is there a normal daily fluctuation of predominant character? Are occasional changes, beyond the normal, to be expected?

Figures 5 to 17, in addition to showing that daily fluctuations are common, also show* that there are usually two types of fluctuation:

1. A long-term range of fluctuation having one set of limits.
2. One or more relatively short term fluctuations having different limits.

Table I was prepared from Figure 5 to present more clearly the different ranges, extents and dates of fluctuation for Beach 18. The record for this beach shows that 79% of the average foreshore slopes fluctuated within a range of 7 - 15% (over a period of approximately 24 weeks) but that 12% of the observations fell within the 3 - 6% range (within one period of 8 weeks) while 9% fell within the

* As mentioned previously, the discussions in this section are only partial and general. In saying that Figures 5 to 17 show something, the authors realize that they may not show the entire picture. With regard to normal and occasional fluctuations, it is conceivable that the true patterns may be different, when lengthier records of beach variation are analyzed. The authors are forced to consider the relatively short patterns of Figures 5 to 17 as being indicative of variation as a whole. All their comments are based upon this assumption.

16 - 20% range (and occurred during two periods of two weeks). Similar patterns of variation are shown for the other beach features of Beach 18. Beach 18, therefore, seems to have experienced a normal, long-term range of fluctuation and also three relatively short-term ranges at higher or lower levels.

Analysis of Figures 5 to 17 shows that analogous variation patterns are found for most of the other beaches, though in some, (16, 17B) the high and/or low groups are either non-existent or scattered. The observations for these beaches (and also some of those adhering to the pattern) are either discontinuous or of relatively brief duration. It is possible that the pattern of variation is not shown completely. It is also possible, as will be discussed later, that beaches having the characteristics of numbers 16, 17B, etc. do not often depart from the normal fluctuation range.

Table I and Figures 5 to 17 indicate the answers to questions 2a and 2b:

1. The features of each beach fluctuate daily, for long terms, within the limits of a "normal" range.
2. Occasionally, each beach will undergo changes such that the midpoint of the daily range is raised or lowered with respect to the normal midpoint (even though the extent of the range

may remain the same). These different ranges may persist for weeks or months, but compared to the normal range, are of short duration.

a. Occasional, extremely short-term changes in individual features may occur during periods of normal fluctuation. These changes are believed to have no appreciable effect upon the limits of the normal range.

A schematic representation of beach changes is shown in Figure 1.

TABLE 1

GROUPING OF VARIATION PERIODS FOR BEACH 18

Average Foreshore Slope

	Total Obser-vations	Range of Values	% of Total	Lates of Occurrence	Remarks
Total Range of Observations	116	3-20	100	10 May-13 Jan	
80% Range of Observations	92	7-15	79	10 May-13 Jan	
Low Group of Observations	14	< 7	12	26 Oct-21Dec	100% occurred
High Group of Observations	10	>15	9	23 Dec-7 Jan 11 Jun-23Jun	33% occurred 90% occurred
Greatest 24-hr. Changes	1 1 1	8(+) 5(-) 5(+)	--- --- ---	21 Dec 23 Dec 15 Jun	
Normal 24-hr. Change	--	1-3(+)	---	------------	

Fs Mean-Sea-Level Width

	Total Obser-vations	Range of Values	% of Total	Dates of Occurrence	Remarks
Total Range of Observations	116	20-120	100	10 May-13 Jan	
80% Range of Observations	93	40-75	100	10 May-13 Jan	
Low Group of Observations	few	<40	neg.		
High Group of Observations	19	>75	16	13 Nov-29Nov 7 Dec-19 Dec	47% occurred 21% occurred
Greatest 24-hr. Changes	1 1	35(-) 30(+)	--- ---	24 Oct 29 Nov	
Normal 24-hr. Change	---	10(±)	---		

TABLE I

GROUPING OF VARIATION PERIODS FOR BEACH 18 (CONTINUED)

Median Grain-Size (D Fs)(Dec)

	Total Obser-vations	Range of Values	% of Total	Dates of Occurrence	Remarks
Total Range of Observations	80	1.48-2.12	100	10 May-13 Jan	
80% Range of Observations	67	1.55-1.85	84	10 May-13 Jan	
Low Group of Observations	10	<1.6	13	12May-18May 17Jun-23Jun	30% occurred 40% occurred
High Group of Observations	15	>1.8	19	15Nov-21Dec	60% occurred
Greatest 24-hr. Changes	1 1 1	0.3(+) 0.22(-) 0.17(+)	--- --- ---	18 May 20 May 21 Nov	
Normal 24-hr. Change	---	0.05(±)	---		

Average Penetration (DFs)

	Total Obser-vations	Range of Values	% of Total	Dates of Occurrence	Remarks
Total Range of Observations	116	1.75-4.00	100	10 May-13 Jan	
80% Range of Observations	92	2.25-3.50	80	10 May-13 Jan	
Low Group of Observations	14	<2.25	13	8 Oct-9 Dec	100%occurred
High Group of Observations	few	>3.50	neg.		
Greatest 24-hr. Changes	1 1	0.75(+) 0.75(+)	--- ---	15 Jul 14 Oct	
Normal 24-hr. Change	--- ---	0.25(-) 0.5(±)	--- ---		

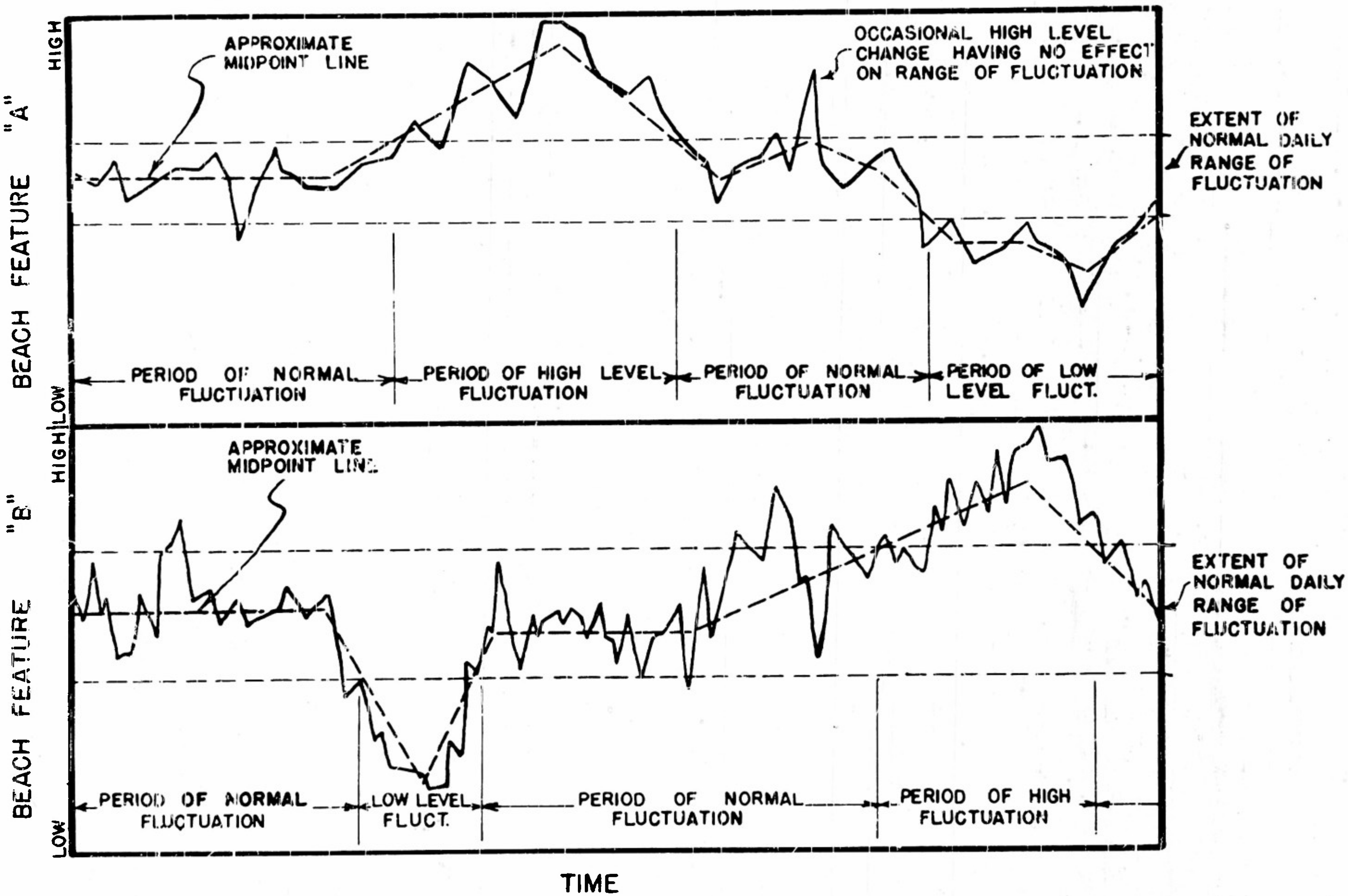

FIGURE I — SCHEMATIC REPRESENTATION of BEACH CHANGES

DISCUSSION OF QUESTIONS 2c AND 2d

What is the extent of the normal daily fluctuation?

Can beaches be classified according

to their normal ranges of fluctuation?

Table I shows that, for Beach 18, the normal 24-hour change in beach features is generally quite small. An analysis of Figures 5 to 17 shows that this situation is generally true. The results of the analysis are presented in Table II.

TABLE II

PROBABLE MAXIMUM NORMAL 24-HOUR

CHANGES IN BEACH FEATURES

Beaches in General (except those similar to 16, 17B, 12B, etc.)			
AFS	Fs MSLW	D50	APR
3%	25'	Slight	0.25"
Beaches similar to 16, 17B, 12B			
AFS	Fs MSLW	D50	APR
0.5%	15'	Very Slight	0.25"

Table I and similar analyses of Figures 5 to 17 also supply data regarding the extent of the normal daily range (80% range) of fluctuation. This data is given as Table III.

Table II provides the answer to Question 2c. Table III provides the answer to Question 2d by showing that beaches can be classified according to the level of their normal ranges of fluctuation. One possible classification is that shown in Table IV.

TABLE III

EXTENT OF NORMAL DAILY RANGE OF FLUCTUATION FOR TEST BEACHES

Arbitrary Name	Beach No.	80% Range of Fluctuation				Remarks
		AFS	Fs MSLW	D_{50}*	APR	
SOFT	12A	10-16	40-125	1.3-1.8 (0.33-1.0)	2-3.5	
	18	9-15	40-75	1.5-1.8 (0.33-0.62)	2.25-3.5	
MEDIUM (SOFT)	5	8-13	15-40	1.4-1.9 (0.24-0.8)	2-3.25	
	6	6-13	35-65	0.9-1.4 (0.8-2.5)	2.75-3.25	Majority Dist.
				1.5-1.9 (0.25-0.62)		Minority Dist.
MEDIUM	13	5-14	50-150	1.8-2.1 (0.16-0.25)	1.75-3.75	All APR on Beach 14 are believed excessive, particularly high ones--APR have odd distributions.
	14	7-11	50-150	1.9-2.1 (0.16-0.25)	1.75-3.75	
	12B	4-11	50-150	1.7-2.1 (0.25-0.40)	1.50-2.50	
	11	6-14	50-125	1.6-1.9 (0.25-0.5)	1.75-2.5	
MEDIUM (HARD)	17B	3-4	125-275	1.8-2.1 (0.16-0.33)	1.25-1.75	
HARD	16	2-3.5	75-225	1.9-2.2 (0.125-0.25)	1.25-1.75	Most low widths due to 0% slope resulting in broad, water-covered foreshores & difficulty in measuring true MSLW.
	17A	3-4	150-300	1.9-2.2 (0.125-0.25)	1.00-1.75	
	15A	3-6	50-200	2.1-2.2 (0.25-0.33)	1.50-2.00	

*First set of figures indicates decimal values (See Figure 10, VolumeI, this Technical Report). Second set of figures indicates actual grain-size in mm.

TABLE IV

POSSIBLE SCHEME FOR CLASSIFYING BEACHES ACCORDING TO RANGES OF VARIATION IN FEATURES

Arbitrary Class	Normal daily range of fluctuation			
	AFS	Fs MSLW	D_{50}*	APR
SOFT	10-15	15-125	1.2-1.8	2.25-3.5
MEDIUM (SOFT)	7-13	15-125	1.4-1.9 (0.25-0.80)	2.25-3.25
MEDIUM	5-10	50-150	1.7-2.0 (0.20-0.40)	2.0-2.75
MEDIUM (HARD)	3-7	100-200	1.8-2.1 (0.16-0.33)	1.5-2.25
HARD	0-4	100-300	2.0-2.2 (.125-0.20)	1.0-1.75

* First set of figures indicates decimal values (See Figure 10, Volume I, this Technical Report). Second set of figures indicates actual grain-size in mm.

DISCUSSION OF QUESTION 2e

Do occasional changes occur with great rapidity or do they cover a reasonable period of time?

As indicated by the midpoint line of Figure 1 and substantiated by Figures 5 to 17, occasional changes that persist for substantial durations usually occur over a reasonable period of time (weeks). However, occasional short-term changes in single features may appear and disappear in a matter of days.

It also appears that major occasional changes are accompanied by increased instability. A correlation of dates of greatest 24-hour changes and dates of high and low fluctuation periods shows that the greatest changes in one or more beach features tend to be associated with the occasional changes of long duration. An inspection of Figures 5 to 17 shows that large changes are accompanied by several fluctuations of lesser extent.

The answer to question 2e, based upon results from the test beaches, is that occasional changes may occur with great rapidity, but changes of relatively long duration usually occur over a period of weeks*, being accompanied by increased instability of beach features.

* Exceptional weather conditions not taken into account.

DISCUSSION OF QUESTION 2f

Do some beach features show greater or less stability than others?

A discussion of comparative stability implies a method of measurement. In a study of this kind, the selection of such a method is subject to considerable interpretation. However, it is believed that the ratio between normal 24 hour change and normal daily range of fluctuation is about as realistic a measurement as any other. Table V provides the necessary data for the determination of such ratios.

According to the method of measurement adopted, perfect stability would be unattainable. (If the 24 hour change were zero, there would be no range of daily normal fluctuation). However, the closer the stability ratio approaches zero, the greater the stability (within the normal range) of the element under consideration.

Table V shows that D_{50} has the lowest, highest, and greatest difference in stability ratios (.10-.70). AFS and APR have identical ranges (0.2-0.5) at a slightly lower level and of slightly less extent. The Fs MSLW has the smallest range and the lowest level (0.15-0.3).

This data is interesting. Any sand beach is the product of waves and currents acting upon the sand. The slope, being a feature of the beach, is also a product of these factors. It is reasonable to assume that waves and currents, acting upon a material that shows relatively little variation, may create a fairly wide variety of slopes (and a corresponding variety of AFS). This would account, on a given beach for the indicated possibility that grain-size could have a much smaller change (low stability ration -- of course, it could have a large ratio on another beach) than the AFS. On such a beach, with a relatively constant grain-size* but changing AFS due to wave and current action, it is also reasonable to assume that the wave-action would affect the densities and moisture contents of the sand at any given point. Consequently, there would be changes in APR (in accordance with the data presented in Volume IV of this technical report). This reasoning is supported by the data of Table V, which shows, that for most beaches, the D_{50} is fairly stable, while on the same beaches, the APR and AFS are much less stable and the Fs MSLW is slightly less stable.

Question 2f can be answered as follows:

1. The median-grain-size of the beach appears to show more stability than any of the other listed factors. However, it is possible in certain cases, that the median sizes can show pronounced instability.
2. The remaining factors (AFS, APR and Fs MSLW) show comparable ranges of stability ratios

* This discussion assumes no changes in grain shape distribution.

with that for the Fs MSLW being slightly lower than the others. This indicates that the Fs MSLW is not quite as dependable a characteristic as the other factors.

TABLE V

DETERMINATION OF PROBABLE STABILITY RATIOS FOR VARIOUS BEACH FACTORS

Beach Number	AFS Total Extent Normal Range	AFS Normal Max. Extent 24 hr. change	AFS Max. Total	Fs MSLW Total Extent Normal Range	Fs MSLW Normal Max. Extent 24 hr. change	Fs MSLW Max. Total	D_{50}* Total Extent Normal Range	D_{50}* Normal Max. Extent 24 hr. change	D_{50}* Max. Total	APR Total Extent Normal Range	APR Normal Max. Extent 24 hr. change	APR Max. Total
18	6	3	.50	35	10	.29	.3	0.05	.17	1.25	0.28	.20
6	7	2	.28	30	5	.17	.4	0.10	.23	0.50	0.25	.50
5	5	1	.18	25	5	.18	.5	0.05	.10	1.25	0.25	.20
12A	6	3	.50	85	20	.23	.5	0.04	.08	1.50	0.25	.33
14	4	2	.48	100	25	.25	.2	--	--	2.00	0.50	.25
13	9	3	.33	100	30	.30	.3	0.01	.03	1.00	0.50	.50
11	8	3	.38	75	20	.28	.3	0.01	.03	0.75	0.25	.33
17A	1	0.5	.45	150	20	.13	.3	0.007	.025	0.75	0.25	.33
17B	1	0.5	.45	150	20	.13	.3	--	--	0.50	0.25	.40
12B	7	2	.29	100	--	--	.4	0.05	.12	0.75	0.25	.33
16	1.5	0.5	.33	150	25	.17	.3	0.02	.07	0.50	0.25	.40
15A	3	1	.33	100	30	.30	.1	0.01	.10	0.75	0.25	.33
Probable range of stability ratios			.20 to .50			.15 to .30			.03 to .20			.20 to .50
							Probable true range of stability ratio		.10 to .70			

* This ratio is misleading. The decimal values of grain-size (See Figure 10, Volume I, this Technical Report), increase in even steps. The corresponding grain-sizes in millimeters decrease according to a logarithmic scale. Consequently, equal values in the columns shown above under D50 give an impression that the stability ratio is exceptionally low. The true stability ratio (in millimeters and practically impossible to determine), is fairly high. For example, the maximum value of 0.2, given in the above Table corresponds generally to an increase or decrease in grain-size of about 50-70% in all ranges (fine, medium, coarse or cross types). The lower value (0.03) is exceptionally low (about 5-10%).

DISCUSSION OF QUESTION 2g

Are normal and occasional changes significant with respect to "trafficability" conditions and/or their estimates?

Table III indicated that the normal daily range of fluctuation varied within rather broad limits, except for "hard" beaches. (See DISCUSSION OF QUESTIONS 2c and 2d). It is quite apparent, after studying the relations between APR and AFS*, D_{50}* and Fs MSLW* that fluctuations within the normal daily range may have an appreciable effect upon APR and AFS and therefore upon the trafficability conditions insofar as both supporting capacity** are concerned. This is particularly true when comparing conditions at the two extremes of the normal daily range. Changes in the features of "hard" beaches, however, do not amount to anything appreciable.

It is indicated by Table II (DISCUSSION OF QUESTIONS 2c and 2d), that the probable maximum normal 24 hour changes in beach features are much lower than the total extent of the daily fluctuation. Accordingly, severe changes in beach conditions (and therefore trafficability) from day to day should not be expected.***

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* For these relations, see Figures 2 to 4c and also Volume I of this report, "Relations Between Beach Features and Beach Conditions".

** See both above reports and Volume IV of this report.

*** Even while a beach is fluctuating within the normal range, occasional short term changes extending beyond the normal range may occur. It is believed that these short term changes do not have an effect upon trafficability conditions that is in proportion to their magnitude (with the possible exception of slope), but that they represent minor transient divergences from the true existing condition.

It is apparent that occasional changes of long term duration will have an overall pronounced effect upon trafficability and trafficability conditions. Superimposed upon this overall effect will be the effects of daily fluctuation within the new range.

Question 2g can be answered to the effect that significant changes in beach conditions do not normally occur within a given 24 hour period, but that over a period of time, even while fluctuating within the normal daily range, significant changes may occur. Occasional changes of long-term duration, which cause the level of daily fluctuation to rise or fall, definitely cause significant changes in trafficability.

DISCUSSION OF QUESTION 3

Are some types of beaches more stable than others?

An inspection of the data included in this report shows that beaches having the characteristics of 16, 17B and 12B are typified by normal daily ranges and maximum 24 hour changes of very low extent. Morever, unlike the other test beaches, they seldom show long-term occasional changes of any appreciable amount unless special factors come into operation.

Consequently,Question 3 may be answered in the affirmative. Beaches that normally have low slopes, broad widths and low median grain-sizes are much more stable than other beaches.

This knowledge is of little practical value from the standpoint of beach trafficability prediction unless prior knowledge of the beach norm is available. Other beaches, during their occasional long-term changes, may be similar to the "hard" beaches in most respects, and it would be difficult to determine whether a given beach with "hard" characteristics were fluctuating within its normal daily range or within an occasional long-term range.

DISCUSSION OF QUESTION 4

Is there any apparent relation between beach changes and possible causative variables?

It has been shown that beach conditions are characterized primarily by change. These changes must involve the interaction of beach material, waves, and currents. It is reasonable to assume that the effects of current will be essentially periodic in general, and that the daily changes in beach conditions result primarily from the interaction of waves and beach material. The possible effect of current is not considered.*

In Technical Report Number 3, Beach Series, Volumes I to III, several statements were made to the effect that variations in wave lengths and frequencies had significant effects upon beaches whether eroding and softening it or "building" and firming it. These conclusions were based upon the results of small qualitative wave tank tests, backed up by a substantial apparent concurrence of opinion.

One of the initial objectives of the current research project was a semi-quantitative investigation of the statements

*In regard to probable changes due to current, it is interesting to note the simultaneous changes in beach conditions on beaches 12A and 12B (Figures 5 and 14) around 10 November. These two beaches are located along a large semi-circular indentation in the coastline within about 3 miles of each other. Because of reef protection and consequent long shore currents acting upon it, Beach 12B is generally fine-grained, gentle and firm while 12A is coarse, steep and soft. During the period following 10 November, beach 12A became gentler, wider and firmer while Beach 12B became steeper, more narrow, coarser and softer. This is believed due to current action acting along the shore from 12A to 12B in combination with wave attack.

made in Technical Report Number 3. This phase of the investigation was based upon the simultaneous accumulation of beach records and wave data on a minimum of six test beaches, together with more wave tank tests. The wave data for the test beaches was to be obtained from existent wave-recorders in operation under the auspices of various governmental and private agencies. Soon after the beginning of the project, it was apparent that wave data would be available on only three beaches. This number was rapidly reduced to one by malfunctions in the recording instruments. Wave data was collected, therefore, on only one beach. Unfortunately, observations on this beach were not obtainable with a frequency greater than twice every three weeks.

The wave tank tests were necessarily limited in both extent and duration. Their conclusions are reported in Appendix B.

Under the above conditions, no intelligent evaluation of the effects of wave variations on beach conditions has been possible. Consequently, the original statements of Technical Report Number 3 must be allowed to stand until proven or disproven. Fragmental data, but little of a conclusive nature, has been collected both in support and in opposition to the statements made.

One implication of the statements in Technical Report Number 3 has been found to be misleading. This implication, influenced to some extent by the results of a survey reported in Technical Report Number 2, is to the effect that, though the firmness, slope and width depends partially upon material characteristics, they are predominantly affected by wave variations. It is believed by the authors, after an evaluation of the material presented in this Technical Report, that firmness, slope and width are primarily related to material characteristics, but are also related, within the range dictated by material characteristics, to variations in wave patterns.

Technical Report Number 3, Beach Series, Volume I included the following passage:

> "All or parts of a beach undergo continuous change. These changes may be slow or abrupt. The long-term changes are seasonal, while the abrupt changes are the result of local storms".

From the data gathered on the various test beaches, on both east and west coasts, it was hoped that some idea concerning the nature of the seasonal change would become evident. Unfortunately, the data proved insufficient for this purpose. An analysis of the available data on the West Coast gives no support to the last sentence of the above statement. There was no apparent seasonal effect of any dominant nature. However, the data was scanty. Any analysis of East Coast data shows a tendency for the beaches to become "softer" during the fall. However, the data is not conclusive enough to support a definite statement to this effect.

The foregoing statement, from Technical Report Number 3, is neither conclusively supported or contradicted. Consequently, it must be allowed to stand.

Question 4 could not be answered <u>conclusively</u> in terms of the data discussed in this report. The authors feel, however, that beach changes are caused primarily by waves, currents and material variations. The major norm of the beach is a function of its material characteristics. The effects of waves and currents are superimposed. These effects may be seasonal in nature.

SECTION III

VALIDITY OF RELATIONS BETWEEN BEACH FEATURES AND BEACH CONDITIONS AS REPORTED IN VOLUME I

GENERAL

It is the objective of this section to investigate the validity of correlations between various beach features that were derived in Volume I of this report.* The objective will be attained if the following question concerning these correlations can be answered adequately:

1. Do the correlations between beach features obtained from instantaneous observations on many beaches persist as the features fluctuate over a long period of time on any given beach?

The correlations investigated are listed below and are shown in Figures 2 to 4c:

1. Average Foreshore Slope vs. Average Penetration (Drying Foreshore).
2. Foreshore Mean-Sea-Level vs. Average Penetration (Width).
3. Median-Grain-Size vs. Average Penetration (Drying Foreshore).
4. Average Foreshore Slope vs. Median-Grain-Size (Drying Foreshore).
5. Foreshore Mean-Sea-Level Width vs. Average Penetration.

The investigation was made by comparing the simultaneous values (interpolated where necessary) of the pertinent features (AFS, APR, etc.) for each date of observation (Figures 5 to 17,

* See Volume I of this Technical Report.

Appendix A) with the 80 percentile envelope for the corresponding correlation (Figures 2 to 4c). If the simultaneous values lay within the 80 percentile envelope, the correlation was considered satisfied. There were a few departures from this procedure:

1. For the correlations shown in Figures 4b and 4c, no 80 percentile envelopes were available.* In these cases, the correlation was considered to be satisfied if the values plotted from the long-term data were within the indicated range of actual values composing Figures 4b and 4c.
2. The mathematical envelope of Figure 2 was broadened upward above an AFS of 10%. This revision was made in view of the apparent scattering of values, in this region, shown on Figure 2 and also in view of experience on a number of beaches having slopes exceeding 10%.
3. The mathematical envelope of Figure 4a was broadened downward below widths of 100 feet. The correlation of Figure 4a implies that very narrow beaches (less than 80 feet) seldom have an APR greater than 3.0". Experience shows that this is not true, narrow beaches often having a higher APR.

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*For explanation, See Technical Report Number 6, Volume I.

4. On several beaches, the divergence "d"* was greatly in excess of 0.4. The correlations of Volume I were based upon values of d ranging between 0.1 and 0.4. They could not be expected to extend to values of d $>$ 0.4. On the bar graphs, periods during which d $>$ 0.4 were subtracted from the total period under consideration, in arriving at the percentages of agreement. (The periods when d was greater than 0.4 are denoted on the bar graphs, Figures 5 to 17).

It is apparent, from Table VI that substantial agreement was found between the correlations of Volume I and the routine observations taken on various test beaches. In practically every case, the percentages of agreement fell within the following ranges:

1. APR vs. AFS - 70% to 90%
2. APR vs. Fs MSLW - 70% to 100%
3. APR vs. D_{50} - 65% to 90%
4. D_{50} vs. AFS - 70% to 100%
5. D_{50} vs. Fs MSLW - 80% to 100%

Two of the first three correlations were in simultaneous agreement 75% to 95% of the time.

The routine beach observations indicated that correlations involving D_{50} (DFs) might be susceptible to more variation than

* See Figure 10, Volume I. The greater the value of d, the less uniformity of gradation.

indicated by Volume I. Such a variation would be quite understandable, considering the infinite range of grain-size and grain-shape distributions that can revolve about a single D_{50}. However, it is possible that the apparent lack of agreement was due to the fact that lack of time prohibited the testing of all the samples obtained from the beaches. Only occasional samples were tested. As a result, one discrepancy could have a disproportionate effect upon the percentage of correlation. This effect can be seen by comparing the bars with the time curves of Figures 5 to 17.

On beaches numbered 17B, 12B and 16, the penetrations were slightly less than that indicated by the correlations of Volume I. Therefore, the error in correlation exhibited by these beaches was on the safe side.

On almost all beaches, during the periods of non-agreement, differences between the observed values and the values indicated by the correlations of Volume I were rather small ($\pm$ 0.25" of penetration). This indicated that the correlations of Volume I were essentially correct.

On two beaches (6 and 14), the agreement between observed values and the correlations of Volume I were quite poor. In the case of beach 14 the lack of agreement was believed to be due to unreliable observations. The observations on beach 6 were considered reliable. No ready explanation of the disagreement on this beach could be advanced beyond the possibility that the beach was composed largely of disintegrated shell (coquina rock) which is prevelent in the locality. Experience has shown that small shell sizes lead to larger penetrations. This possible cause could not be proven or disproven from the available data at the time of analysis.

In general, considering the many factors that entered into the analysis of agreement, the correlations themselves, and the taking of observations, the routine observations were considered to show substantial agreement with the correlations of Volume I.

TABLE VI

EXTENT OF AGREEMENT BETWEEN CORRELATIONS OF VOLUME I AND ROUTINE BEACH OBSERVATIONS

Beach Number	% Time that correlations checked					% Time that 2 of first 3 correlations checked	% Time that 1 of first 3 correlations checked	% Time that none of first 3 correlations checked
	APR vs. AFS	APR vs. Fs MSLW	APR vs. D_{50}	D_{50} vs. AFS	D_{50} vs. Fs MSLW			
12A	74	71	65	80	80	84	97	3
18	81	84	67	88	90	85	98	2
5	75	100	68*	85*	84*	89*	100*	0
6**	30	95	56	60	83	63	98	2
13	66	92	77	62	94	87	99	1
14**	30	44	31	40	87	30	58	12
11	61	86	66	78	96	82	100	0
15B	87	100	72***	71	58	90	100	0
17A	83*	95	84*	100*	100*	91*	100*	0
17B	80	71	63*	91*	62*	78*	77*	23
16	88	90	90	100	100	93	98	2
15A	73	75	74	85	88	90	95	5

* Lengthy periods when D 0.4
** See Text
***Lengthy periods when beach composed of gravel and very coarse sand

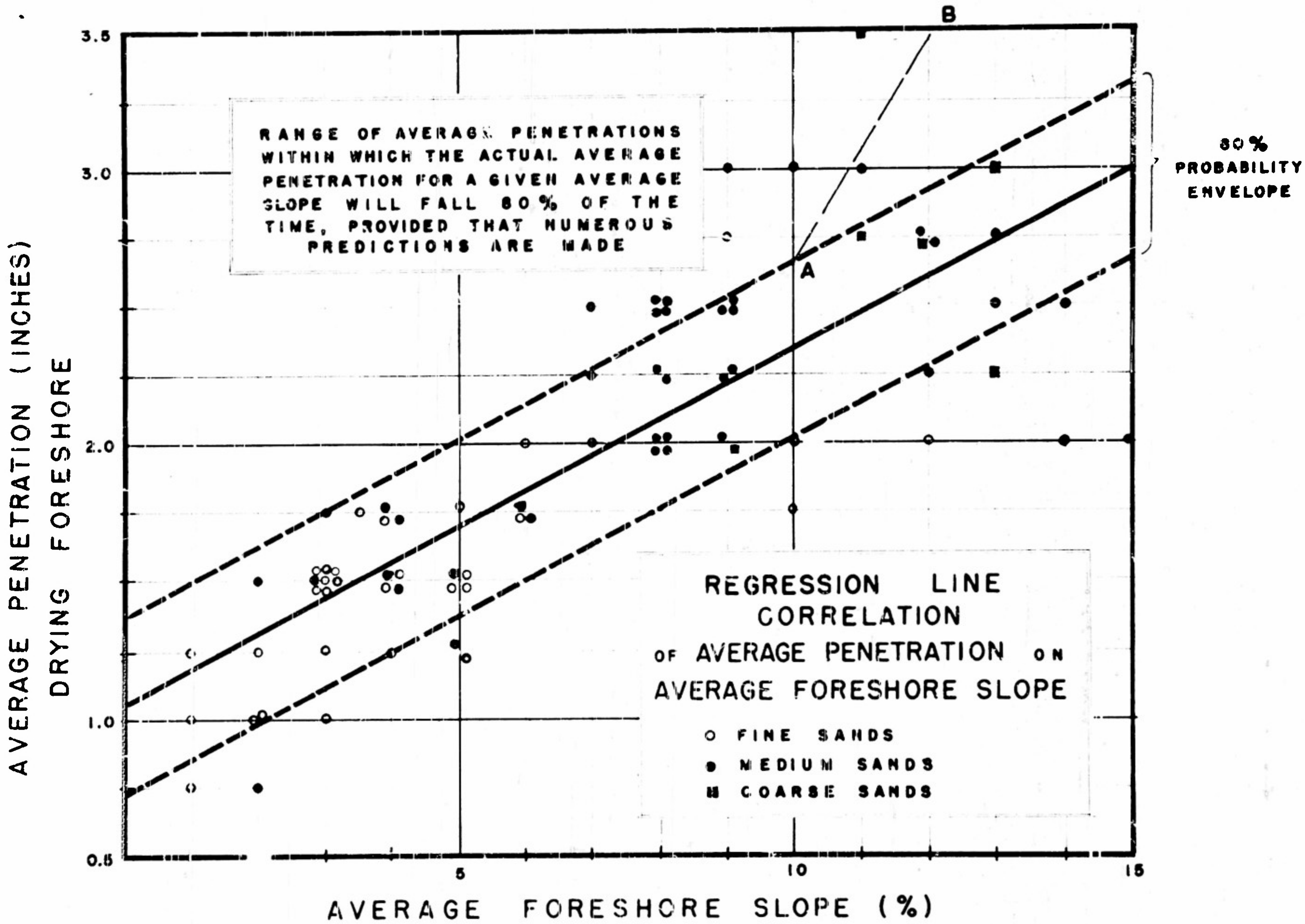

RANGE OF AVERAGE PENETRATIONS WITHIN WHICH THE ACTUAL AVERAGE PENETRATION FOR A GIVEN AVERAGE SLOPE WILL FALL 80% OF THE TIME, PROVIDED THAT NUMEROUS PREDICTIONS ARE MADE
80% PROBABILITY ENVELOPE
A
B
REGRESSION LINE CORRELATION OF AVERAGE PENETRATION ON AVERAGE FORESHORE SLOPE
FINE SANDS
MEDIUM SANDS
COARSE SANDS
AVERAGE PENETRATION (INCHES) DRYING FORESHORE
3.5
3.0
2.0
1.0
0.5
5
10
15
AVERAGE FORESHORE SLOPE (%)

FIGURE 2

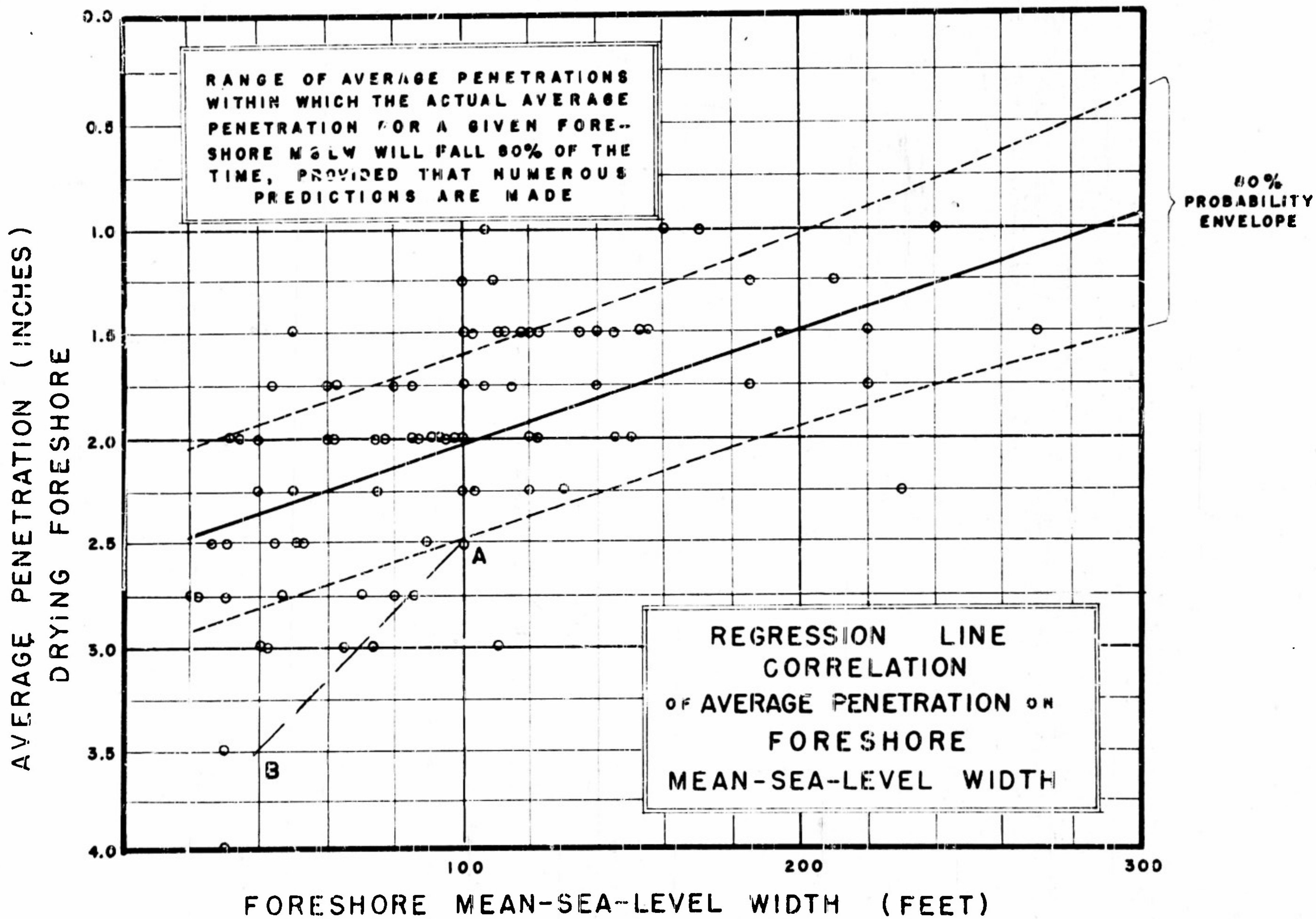
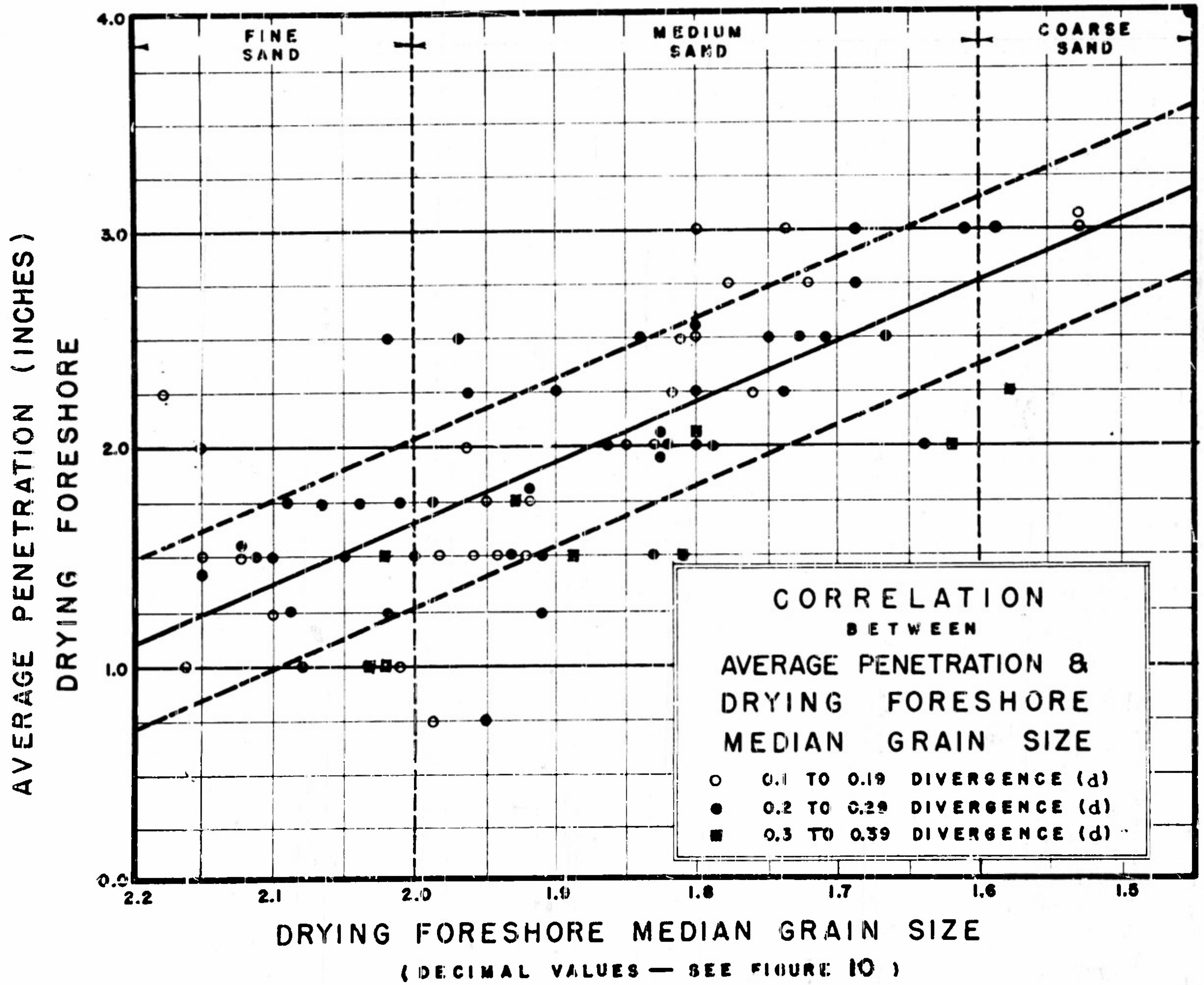

0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
100
200
300
AVERAGE PENETRATION (INCHES)
DRYING FORESHORE
FORESHORE MEAN-SEA-LEVEL WIDTH (FEET)
RANGE OF AVERAGE PENETRATIONS WITHIN WHICH THE ACTUAL AVERAGE PENETRATION FOR A GIVEN FORESHORE MSLW WILL FALL 80% OF THE TIME, PROVIDED THAT NUMEROUS PREDICTIONS ARE MADE
80% PROBABILITY ENVELOPE
A
B
REGRESSION LINE CORRELATION OF AVERAGE PENETRATION ON FORESHORE MEAN-SEA-LEVEL WIDTH

FIGURE 3



AVERAGE PENETRATION (INCHES)
DRYING FORESHORE
4.0
3.0
2.0
1.0
0.0
FINE SAND
MEDIUM SAND
COARSE SAND
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
CORRELATION
BETWEEN
AVERAGE PENETRATION &
DRYING FORESHORE
MEDIAN GRAIN SIZE
0.1 TO 0.19 DIVERGENCE (d)
0.2 TO 0.29 DIVERGENCE (d)
0.3 TO 0.39 DIVERGENCE (d)
DRYING FORESHORE MEDIAN GRAIN SIZE
(DECIMAL VALUES — SEE FIGURE 10)

FIGURE 4a

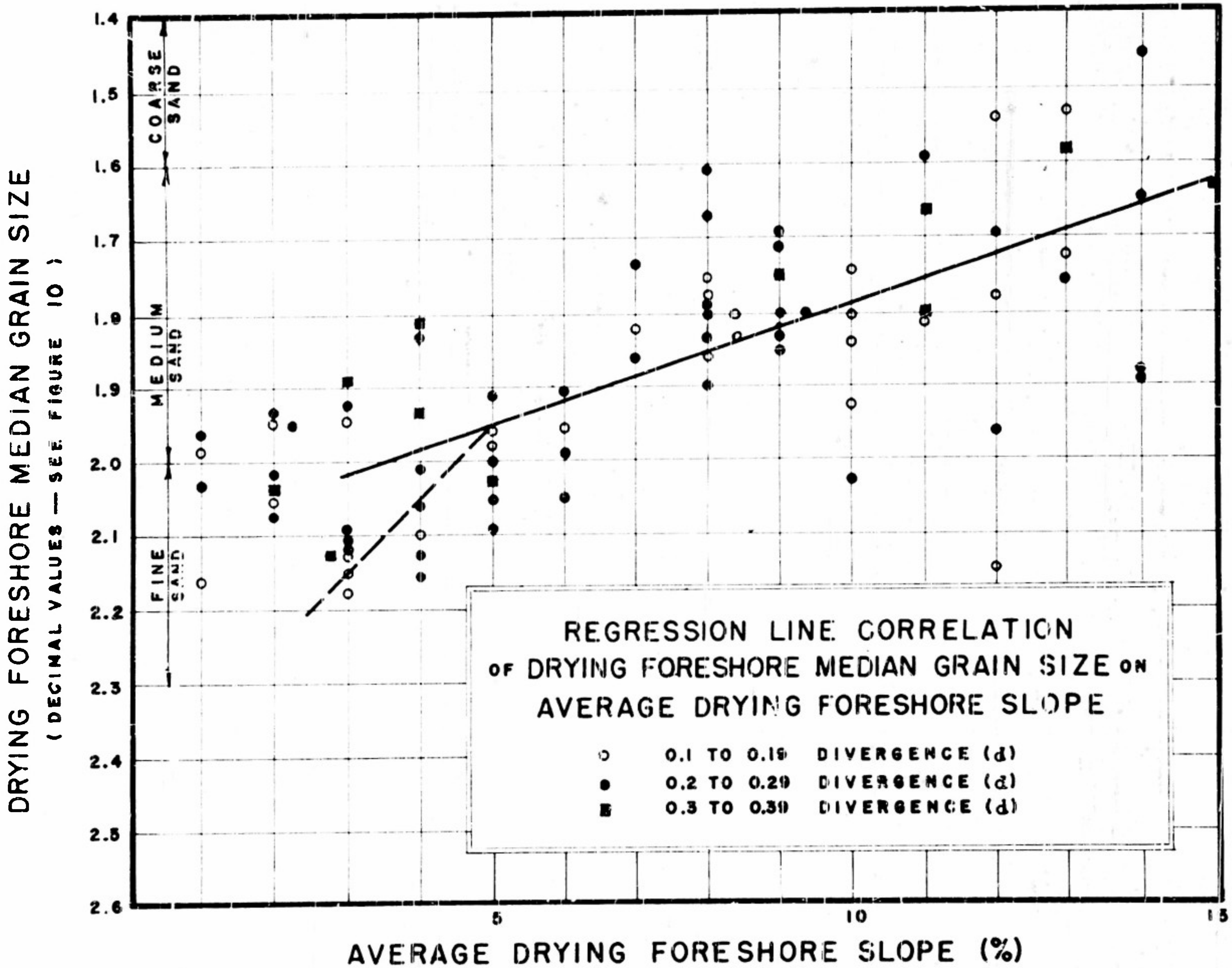
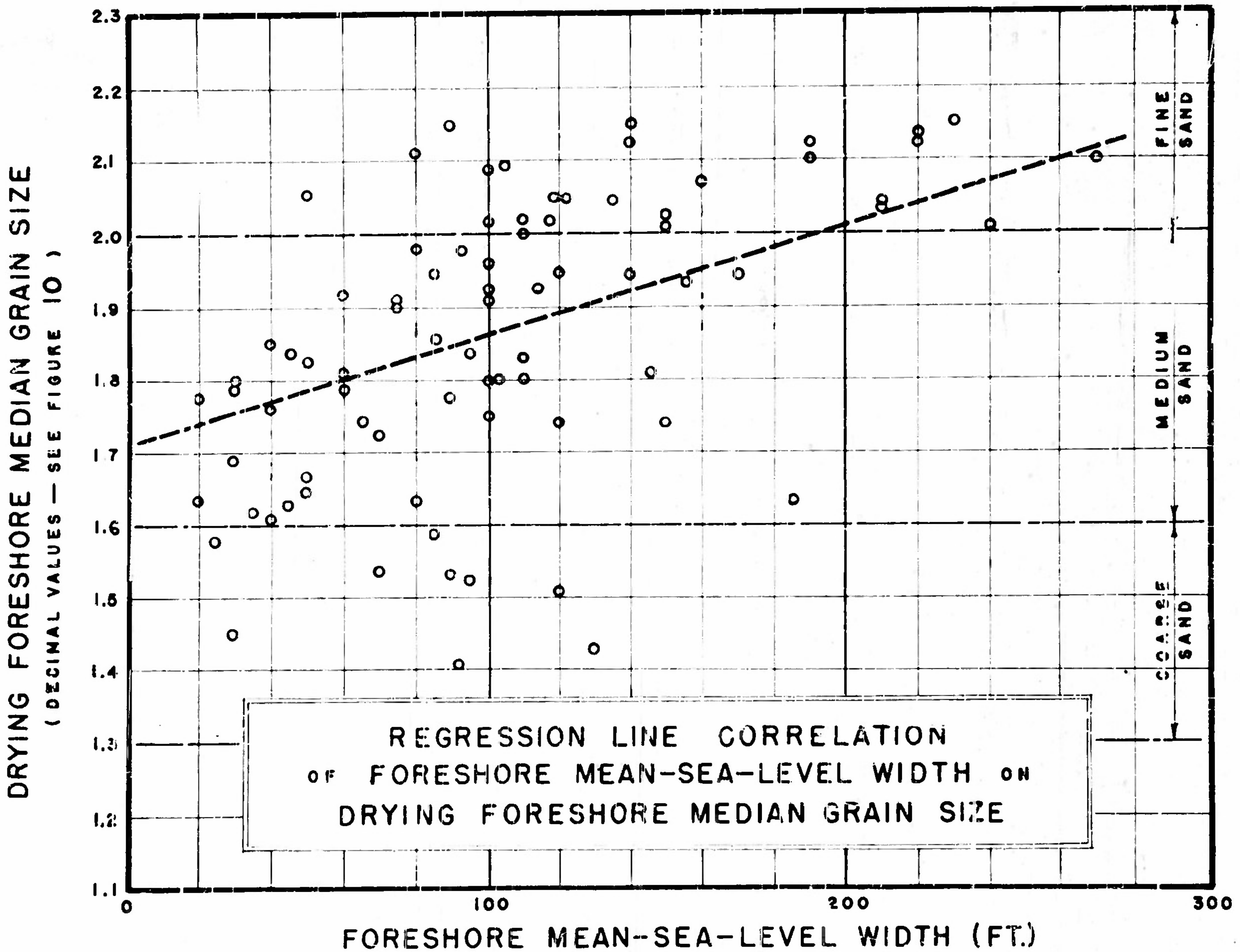

DRYING FORESHORE MEDIAN GRAIN SIZE
(DECIMAL VALUES — SEE FIGURE 10)
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
COARSE SAND
MEDIUM SAND
FINE SAND
5
10
15
AVERAGE DRYING FORESHORE SLOPE (%)
REGRESSION LINE CORRELATION
OF DRYING FORESHORE MEDIAN GRAIN SIZE ON
AVERAGE DRYING FORESHORE SLOPE
0.1 TO 0.19 DIVERGENCE (d)
0.2 TO 0.29 DIVERGENCE (d)
0.3 TO 0.39 DIVERGENCE (d)

FIGURE 4b



REGRESSION LINE CORRELATION
OF FORESHORE MEAN-SEA-LEVEL WIDTH ON
DRYING FORESHORE MEDIAN GRAIN SIZE
DRYING FORESHORE MEDIAN GRAIN SIZE
(DECIMAL VALUES — SEE FIGURE 10)
FORESHORE MEAN-SEA-LEVEL WIDTH (FT.)
FINE SAND
MEDIUM SAND
COARSE SAND
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
0
100
200
300

FIGURE 4c

SECTION IV

CONCLUSIONS

GENERAL

This section lists the conclusions drawn from data discussed in Sections I and II and Appendix B.

The conclusions are presented in three subdivisions:

1. Conclusions regarding the variations and stability of beach conditions.
2. Conclusions regarding the validity of relations between beach features and beach conditions that were presented in Volume I.
3. Conclusions based upon the results of the wave tank tests.

CONCLUSIONS REGARDING THE VARIATION AND STABILITY OF BEACH CONDITIONS

The conclusions on this subject are as follows:

1. Beach conditions are characterized primarily by fluctuations with respect to time, approaching static conditions only for comparatively short periods.

   a. Beaches which are normally broad, gentle and fine-grained tend to show less fluctuation than other beaches and are essentially static for appreciable periods.

2. The features of each beach fluctuate daily, for long periods, within the limits of a "normal" range.

3. Occasionally, each beach will undergo changes that the midpoint of the daily range is raised or lowered with respect to the midpoint of the normal range. These occasional different ranges may persist for weeks or months, but compared to the normal range, are of short duration.

   a. Occasional, extremely brief changes in individual features may occur during periods of normal fluctuation. These changes, with the exception of those involving slope, are believed to have no appreciable effect on beach conditions.

4. The probable maximum normal 24-hour changes are as shown in Table VII.

5. The probable total extent of the normal daily range is as shown in Table VIII.

6. Beaches can be classified according to the level of their normal daily range of fluctuation in a manner similar to that shown in Table IX.

7. Occasional changes may occur with great rapidity (24-48 hours), but changes of relatively long duration usually occur over a period of weeks, being accompanied by increased instability of beach features. Exceptional weather conditions may invalidate this rule.

8. The grain-sizes of the sand composing the drying foreshore seem to have a fair amount of stability, greater than any other beach feature. However, the grain-size and gradation may change radically and rapidly upon occasion.

9. Significant changes in beach conditions do not normally occur within a given 24-hour period, but over a period of time, even while fluctuating within the normal daily range, significant changes may occur.

10. Occasional changes of long-term duration definitely cause significant changes in trafficability.

11. Beaches that are normally characterized by very low slopes (0-3%), broad widths (200-300') and fine grain-sizes (fine sands) are much more stable than other beach types.

12. The characteristic range of fluctuation for beaches depends upon the characteristics (sizes particularly) of the material composing the beach. Upon this characteristic range, there are superimposed variations due to changes in waves and currents.

13. No conclusive specific relations between beach conditions and causative variables such as wave changes (including seasonal variations) and current changes were obtainable from the data discussed in this report.

TABLE VII

PROBABLE MAXIMUM NORMAL 24-HOUR

CHANGES IN BEACH FEATURES

Beaches that are normally broad, gentle and fine-grained			
AFS	Fs MSLW	D_{50}	APR
0.5%	15'		0.25"
Other Beaches			
3%	25'		0.25"

TABLE VIII

PROBABLE TOTAL EXTENT OF NORMAL DAILY RANGE OF CHANGES IN BEACH FEATURES

Beaches that are normally broad, gentle and fine-grained			
AFS	Fs MSLW	D_{50}	APR
1-2%	100-150'	0.1-0.3	0.5-0.75"
Other Beaches			
5-7%	25-100'	0.3-0.5	1.0-1.5"

TABLE IX

A POSSIBLE CLASSIFICATION OF BEACHES ACCORDING TO NORMAL RANGES OF FLUCTUATION IN BEACH FEATURES

Arbitrary Class Name	Normal daily range of fluctuation AFS	Fs MSLW	D_{50}*	APR
SOFT	10-15	15-125	1.2-1.8 (0.33-1.25)	2.25-3.5
MEDIUM (SOFT)	7-13	15-125	1.4-1.9 (0.25-0.80)	2.25-3.25
MEDIUM	5-10	50-150	1.7-2.0 (0.25-0.80)	2.0-2.75
MEDIUM (HARD)	3-7	100-200	1.8-2.1 (0.16-0.33)	1.5-2.25
HARD	0-4	100-300	2.0-2.2 (0.125-0.20)	1.0-1.75

* These figures refer to decimal intercepts. See note at bottom of TABLE V. If a second set of figures is given, it refers to actual diameters in millimeters.

CONCLUSIONS REGARDING THE VALIDITY OF CORRELATIONS PRESENTED IN VOLUME I

The correlations presented in Volume I, between beach features and beach conditions, were substantiated to a significant degree by the results of the routine beach observations.

Except for one or two beaches, where special conditions were known to exist or were suspected, the following percentages of agreement with Volume I correlations were obtained from the routine beach data:

1. APR vs. AFS - 70% to 90% of the time
2. APR vs. Fs MSLW - 80% to 100% "
3. APR vs. D_{50} - 65% to 90% "
4. D_{50} vs. AFS - 65% to 100% o "
5. D_{50} vs. Fs MSLW - 65% to 100% "

Two of the first three correlations were in agreement with the correlations 80-95% of the time.

The routine beach data indicated that there may be less agreement between various features and D_{50} than is indicated by the correlations presented in Volume I. This is to be expected. D_{50} may be the same for an infinite variety of grain-shape distributions and grain-size distributions, all of which may have effects on APR, AFS and Fs MSLW. It is believed that estimates based primarily upon median grain-size should be considered slightly less accurate than indicated by the correlations of Volume I.

The routine beach data indicates that multiple estimates of beach trafficability, as outlined in Volume I, may be used with a degree of confidence close to the 80% specified.

CONCLUSIONS REGARDING THE RESULTS OF THE WAVE TANK TESTS

The following explanatory remarks, appearing in the test report* are of interest:

> "It should be understood that the writer intends nothing more than a report of experimental findings. The statements made under "Analysis of Experimental Data" are intended to apply within the experimental limits of this study, and for the particular procedures employed.
>
> If the reader considers this study as a model of ocean waves of large dimensions acting upon actual beaches, it is to be remembered that requirements for similarity have been violated, just as they are violated in most hydraulic models with movable beds. The linear dimensions of large ocean waves would be considerably reduced in the model, while the finest of the test sands was an actual beach sand.
>
> The value of the study lies in its indication of trends in the response of sands to wave action. It is the writer's belief that this study makes a substantial contribution in qualitative information concerning the influence of sand characteristics, wave characteristics, and initial beach slope upon beach profiles and beach stability."

Keeping in mind the above remarks, a number of conclusions can be obtained from the wave tank report. These conclusions are based upon the "Analysis of Experimental Data" in the original test report. While reading the conclusions, it is convenient to remember that test sands I, III and IV have very similar gradations (See Figure 18) but are increasingly coarser, while sand IV is midway between sand I and III in size, but has a better gradation.

The conclusions are as follows:

1. Grain-size is of dominant importance insofar as beach features are concerned.
2. Fine sands have the greatest tendency to form ripples. Coarse sands seldom form ripples.
3. Fine sands have the greatest tendency to form multiple offshore bars.
4. The inter-action of waves and sand is directed toward the creation of a "stable" profile characteristic of the material being acted upon.
5. Under wave tank conditions, fine sands show a tendency to have the least penetration while coarse sands show the greatest penetrations.
6. An <u>increase</u> in relative wave height or steepness is associated with an increase in the extent of both scour and deposition.
7. A <u>decrease</u> in relative frequency is also associated with an increase in the extent of both scour and deposition.
8. Scour and deposition are accomplished by surf turbidity.

APPENDIX A

CHARTS SHOWING ROUTINE OBSERVATIONS AND CORRELATION GRAPHS

GENERAL

The charts on the following pages show the time observations taken on the test beaches, as well as the correlation bar graphs.

On the charts, the horizontal axis is time. The line graphs indicate the actual changes in various beach features according to the legend on the left of the charts. The bar graphs indicate correlation. If the correlations of Figures 2 to 4c were satisfied, the bars were filled in. If the correlations were unsatisfied, the bar was left blank. An agreement of 100% would be represented by a solid black bar across the entire time interval of observations.

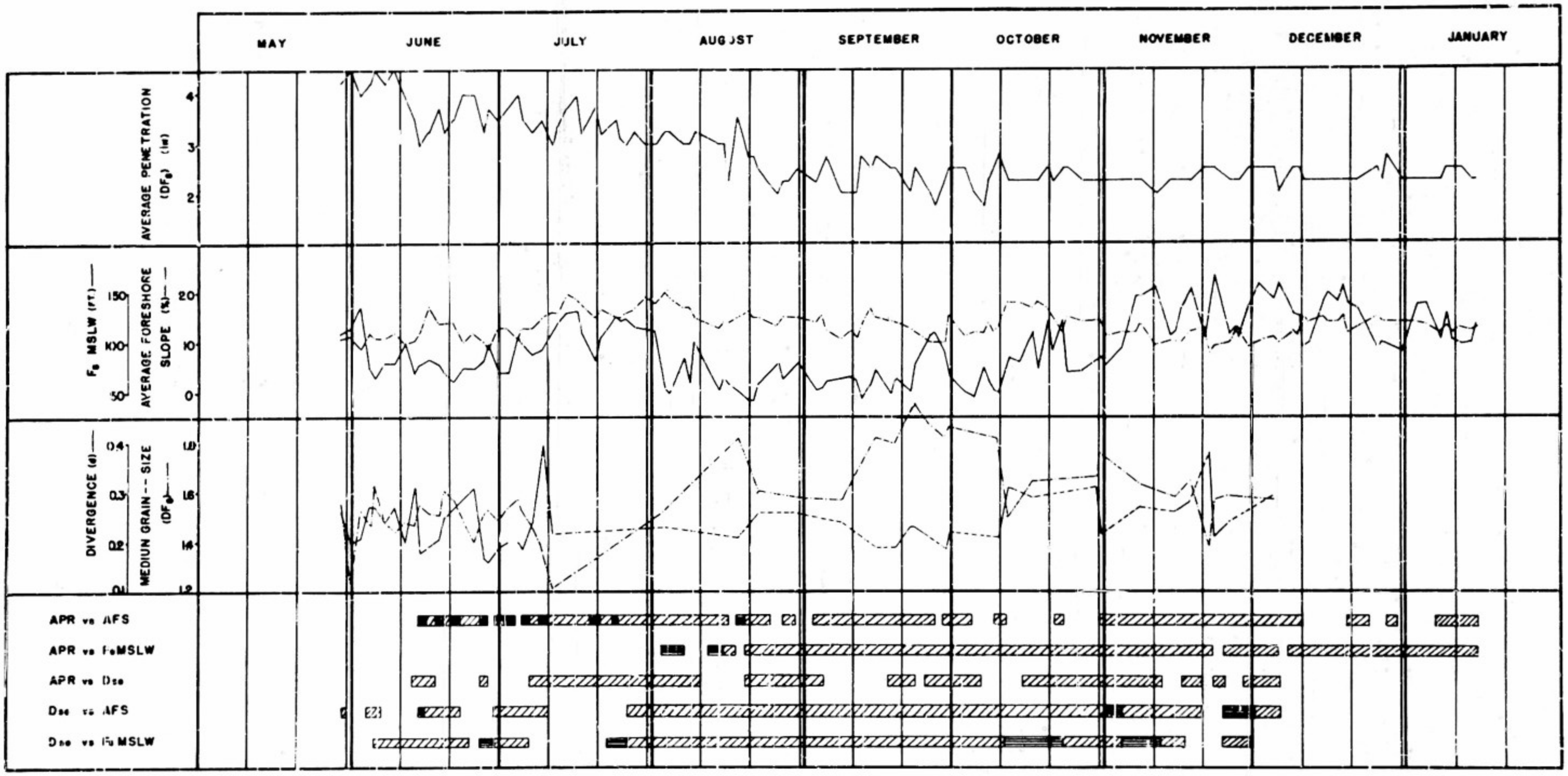


FIGURE 6

TIME CHARTS AND CORRELATION GRAPHS

BEACH 12A

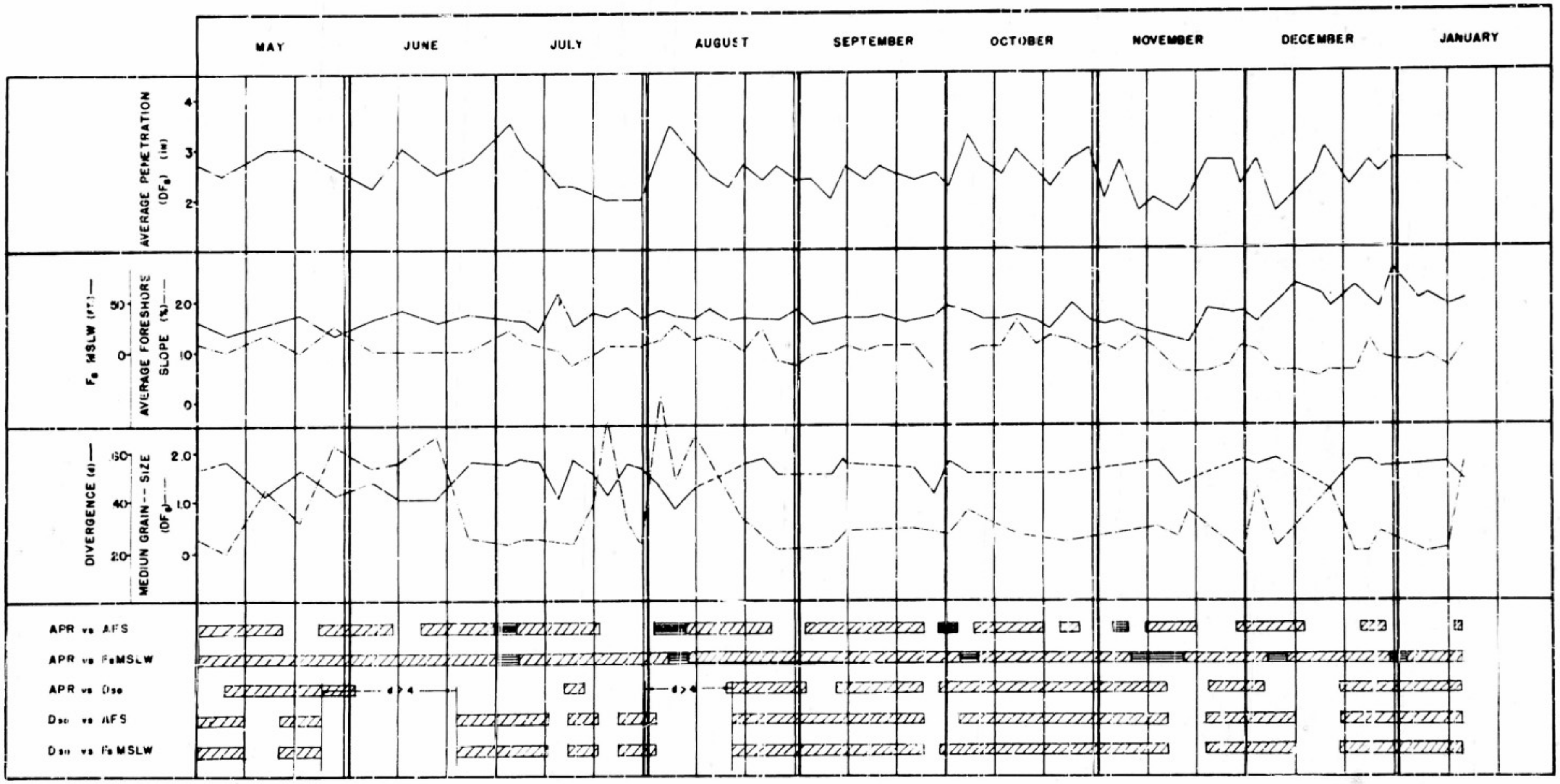


FIGURE 7

TIME CHARTS AND CORRELATION GRAPHS

BEACH 5

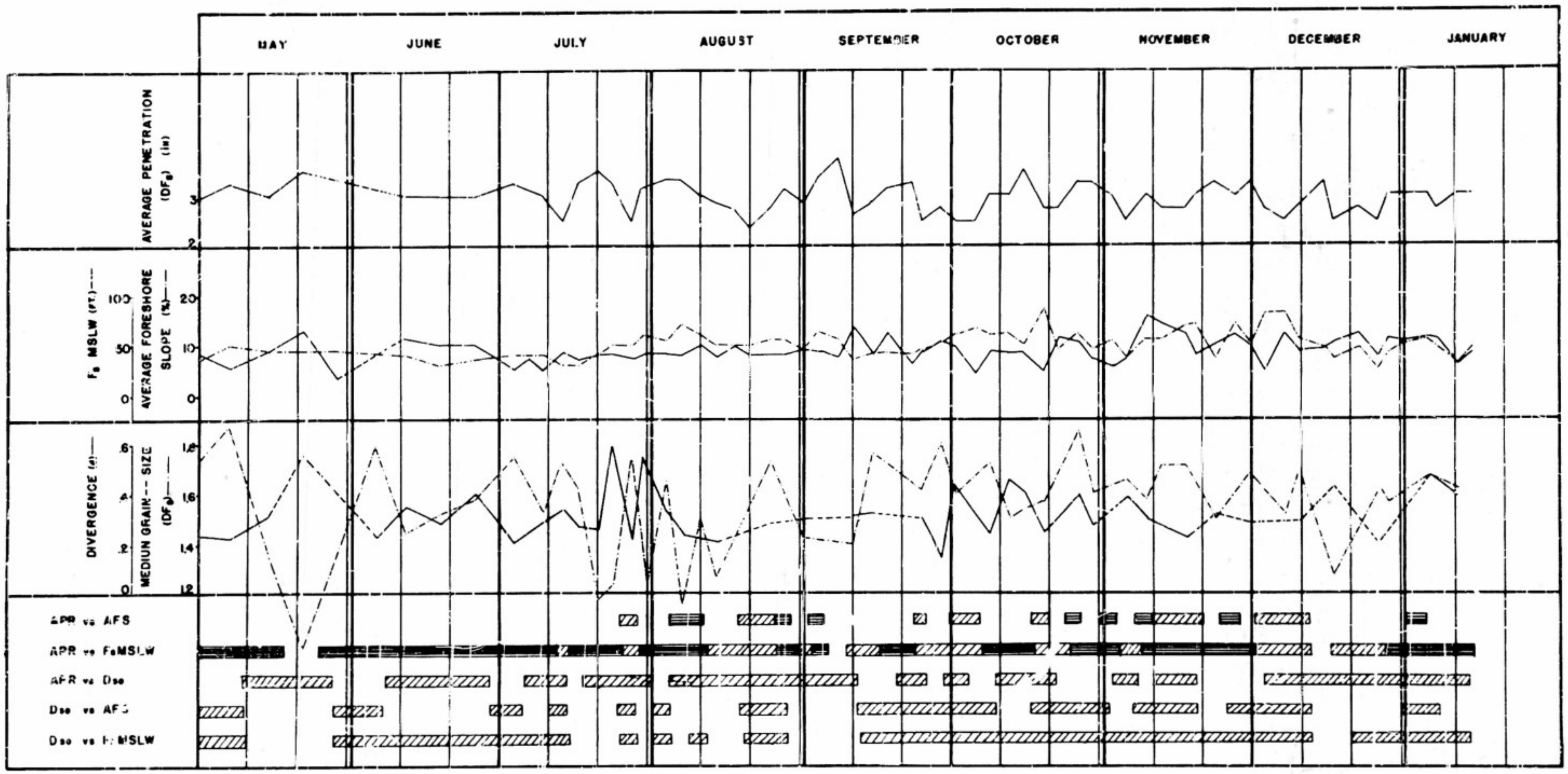


FIGURE 8

TIME CHARTS AND CORRELATION GRAPHS

BEACH 6

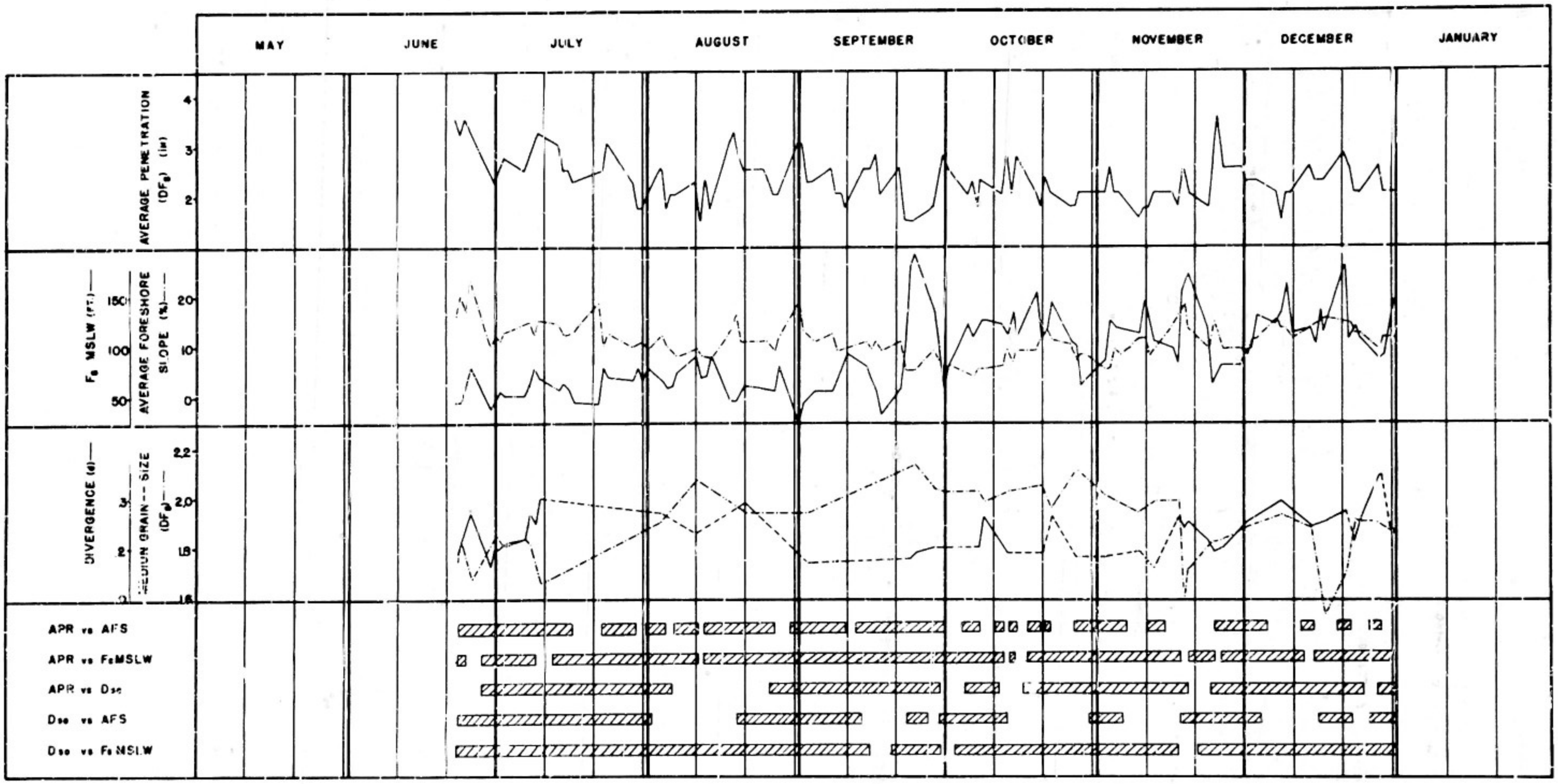


FIGURE 9

TIME CHARTS AND CORRELATION GRAPHS

BEACH 13

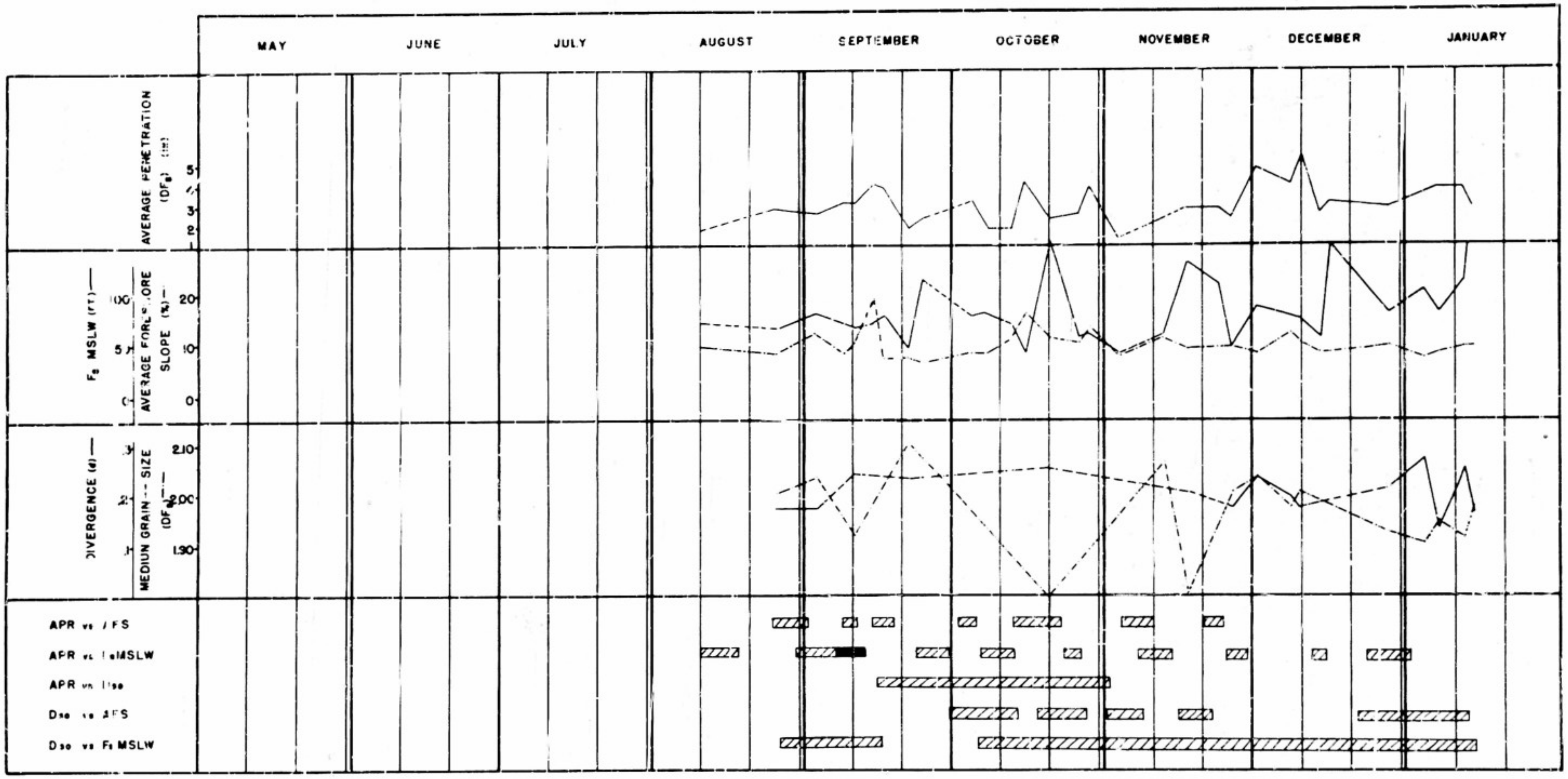


FIGURE 10

TIME CHARTS AND CORRELATION GRAPHS

BEACH 14

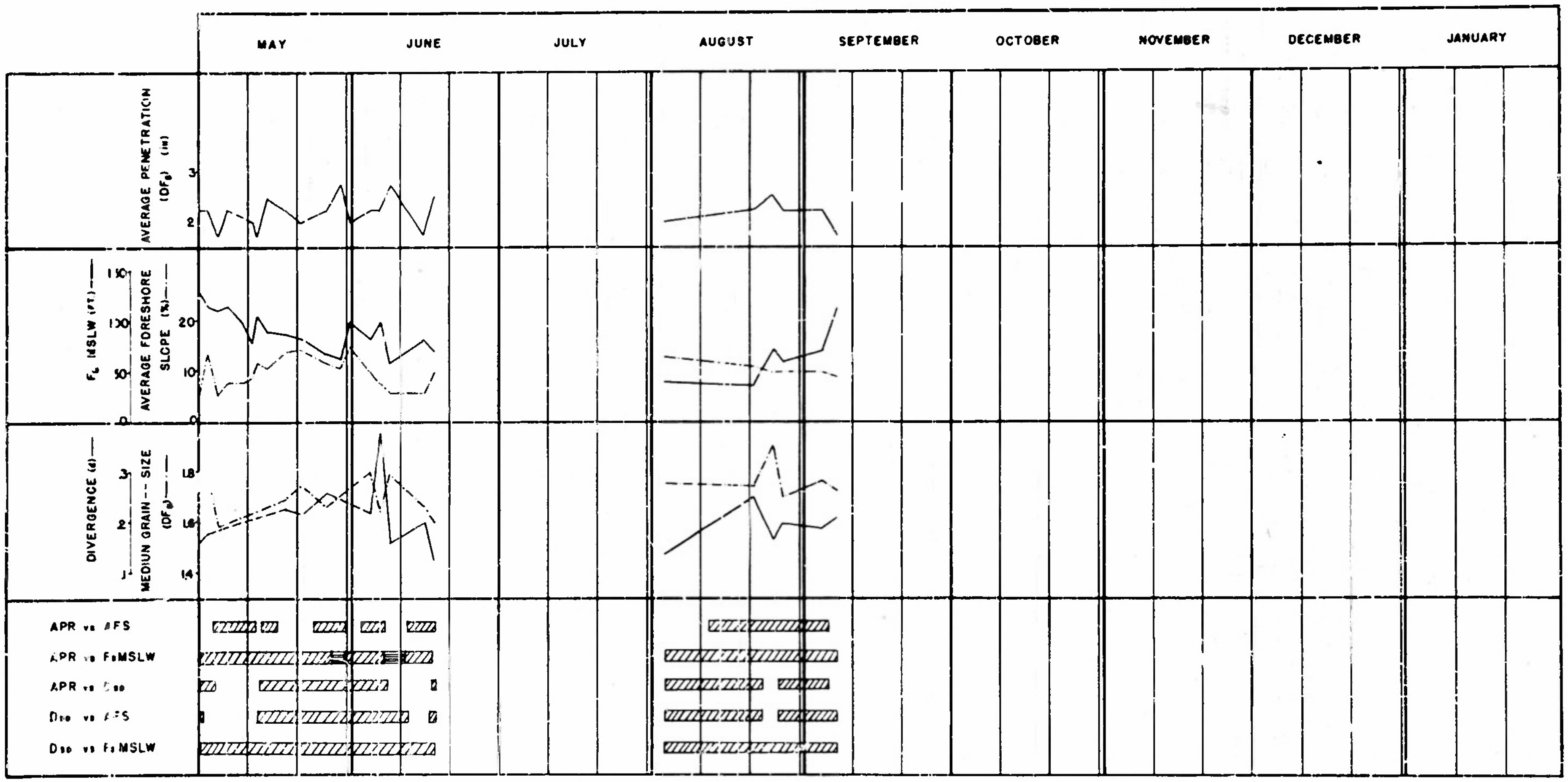


FIGURE II

TIME CHARTS AND CORRELATION GRAPHS

BEACH C

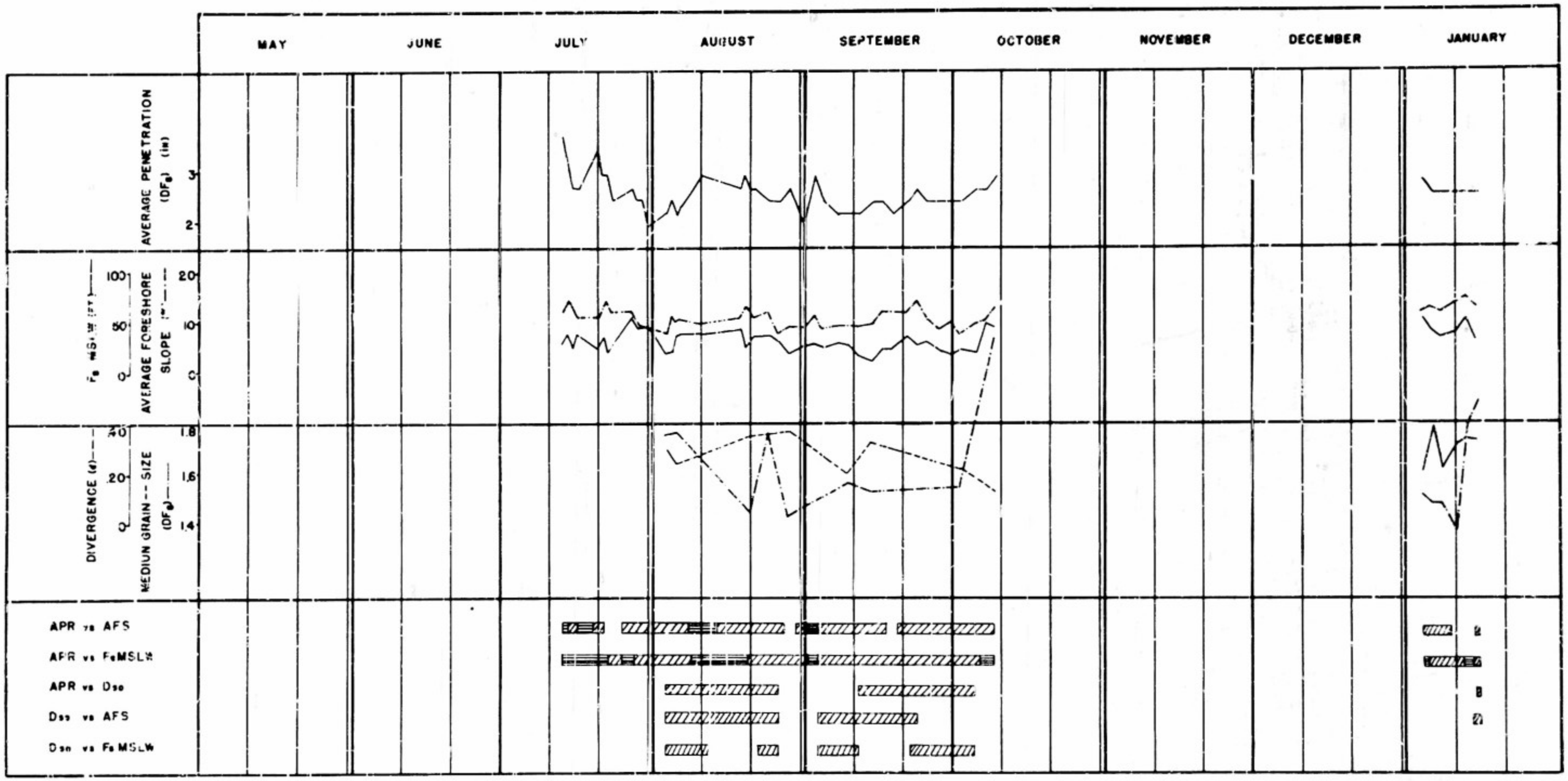


FIGURE 12

TIME CHARTS AND CORRELATION GRAPHS

BEACH 15B

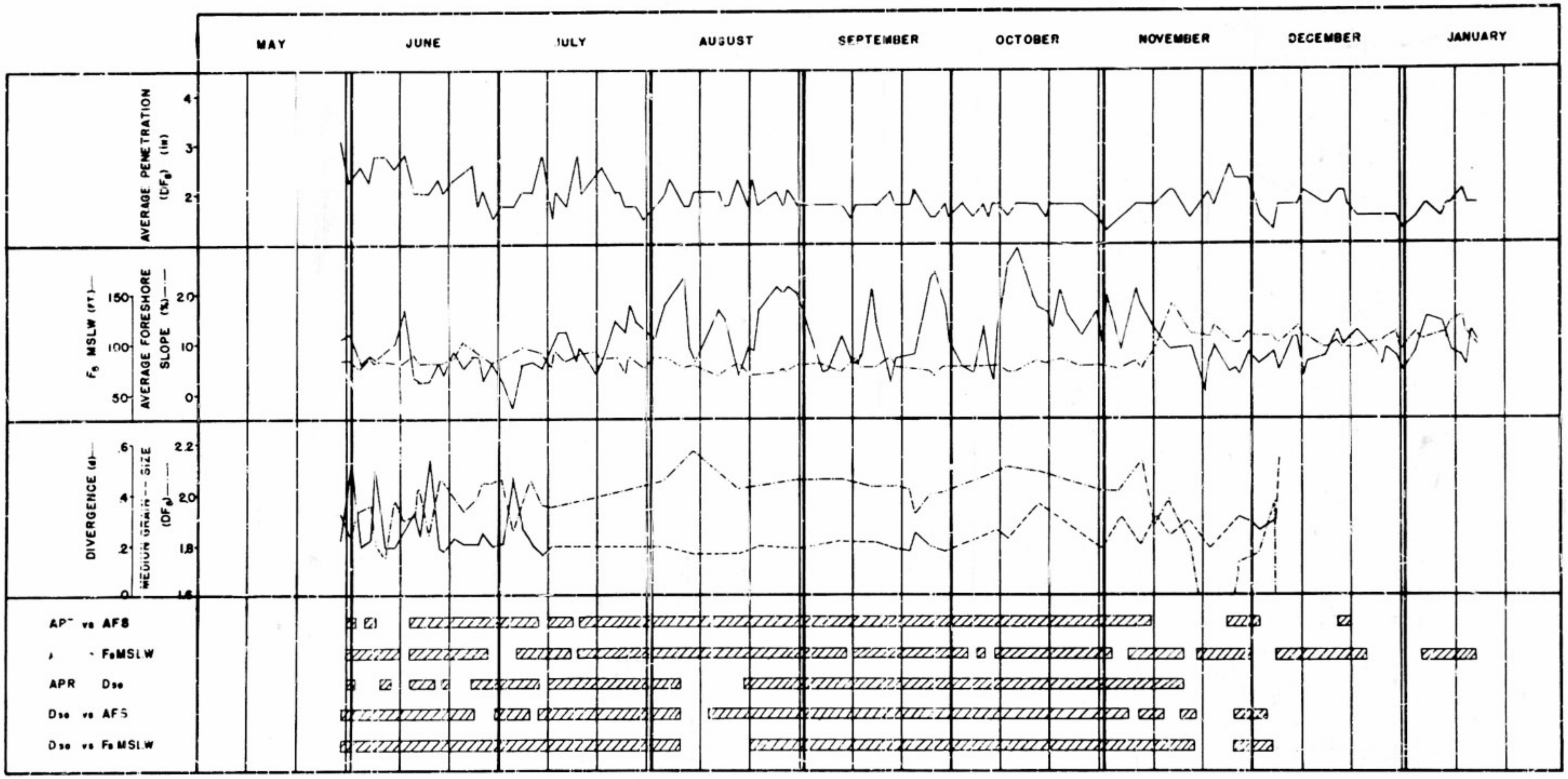


FIGURE 13

TIME CHARTS AND CORRELATION GRAPHS

BEACH 12B

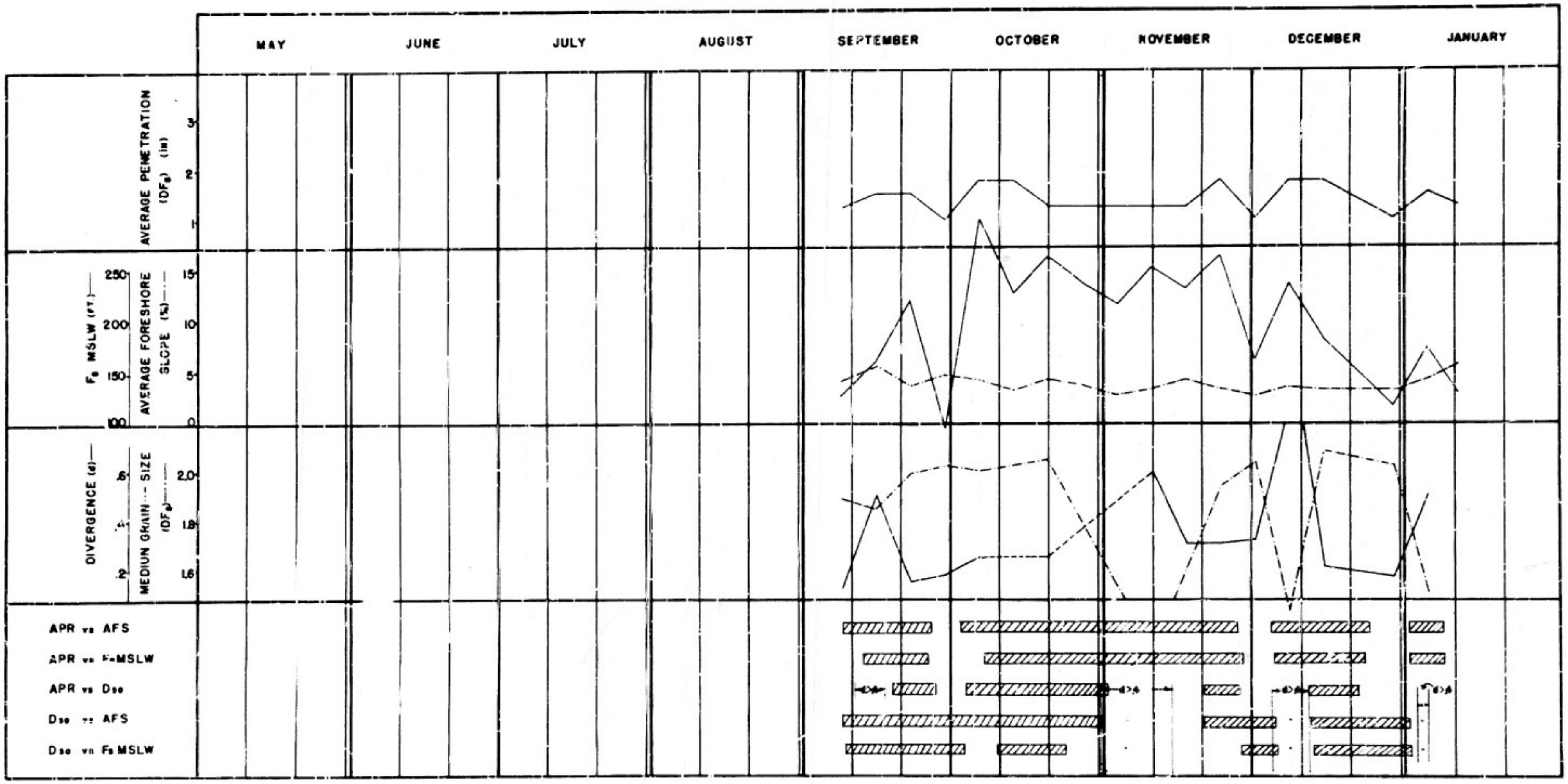


FIGURE 14

TIME CHARTS AND CORRELATION GRAPHS

BEACH 17B

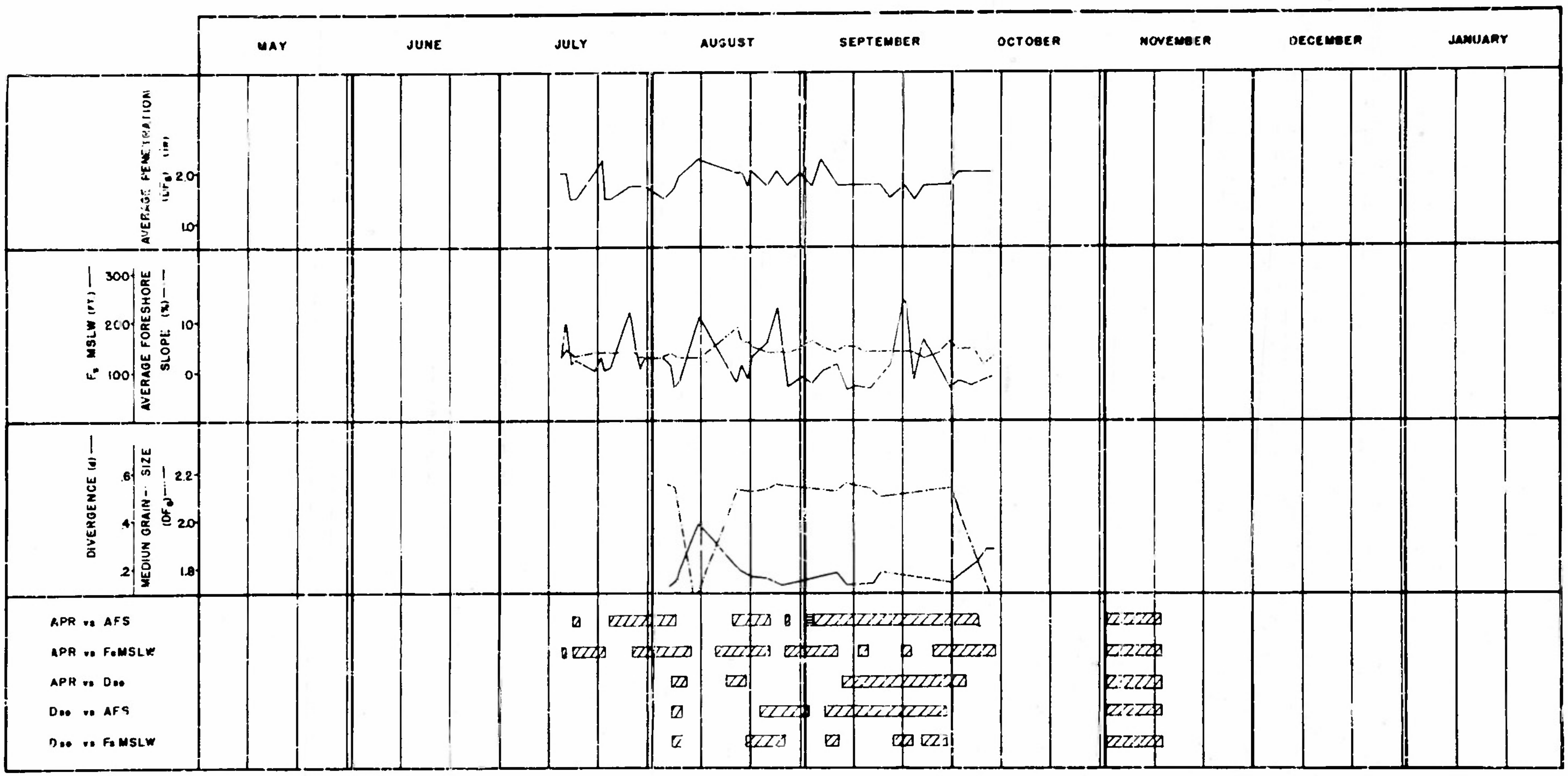


FIGURE 15

TIME CHARTS AND CORRELATION GRAPHS

BEACH 15A

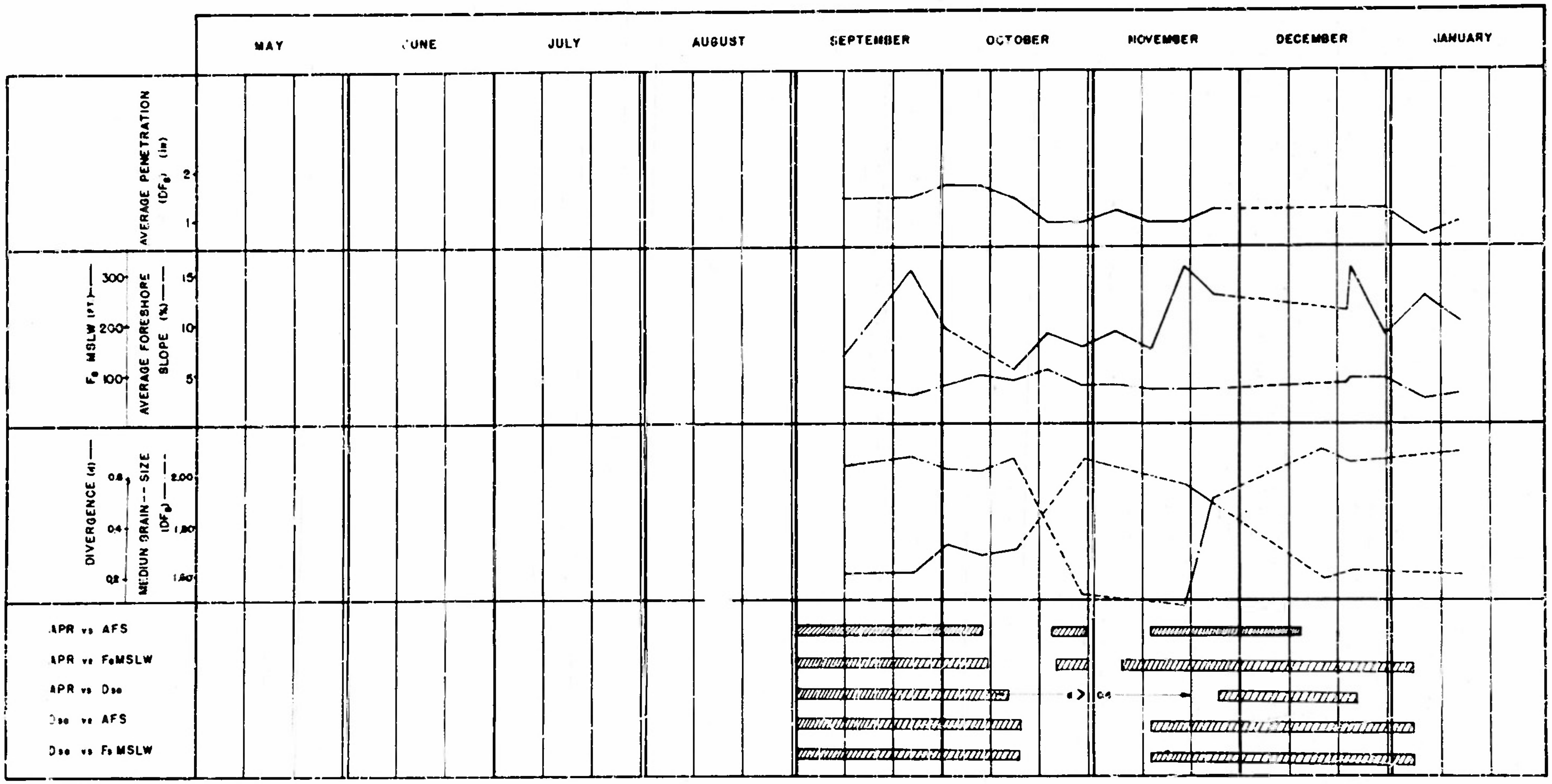


FIGURE 16

TIME CHARTS AND CORRELATION GRAPHS

BEACH 17A

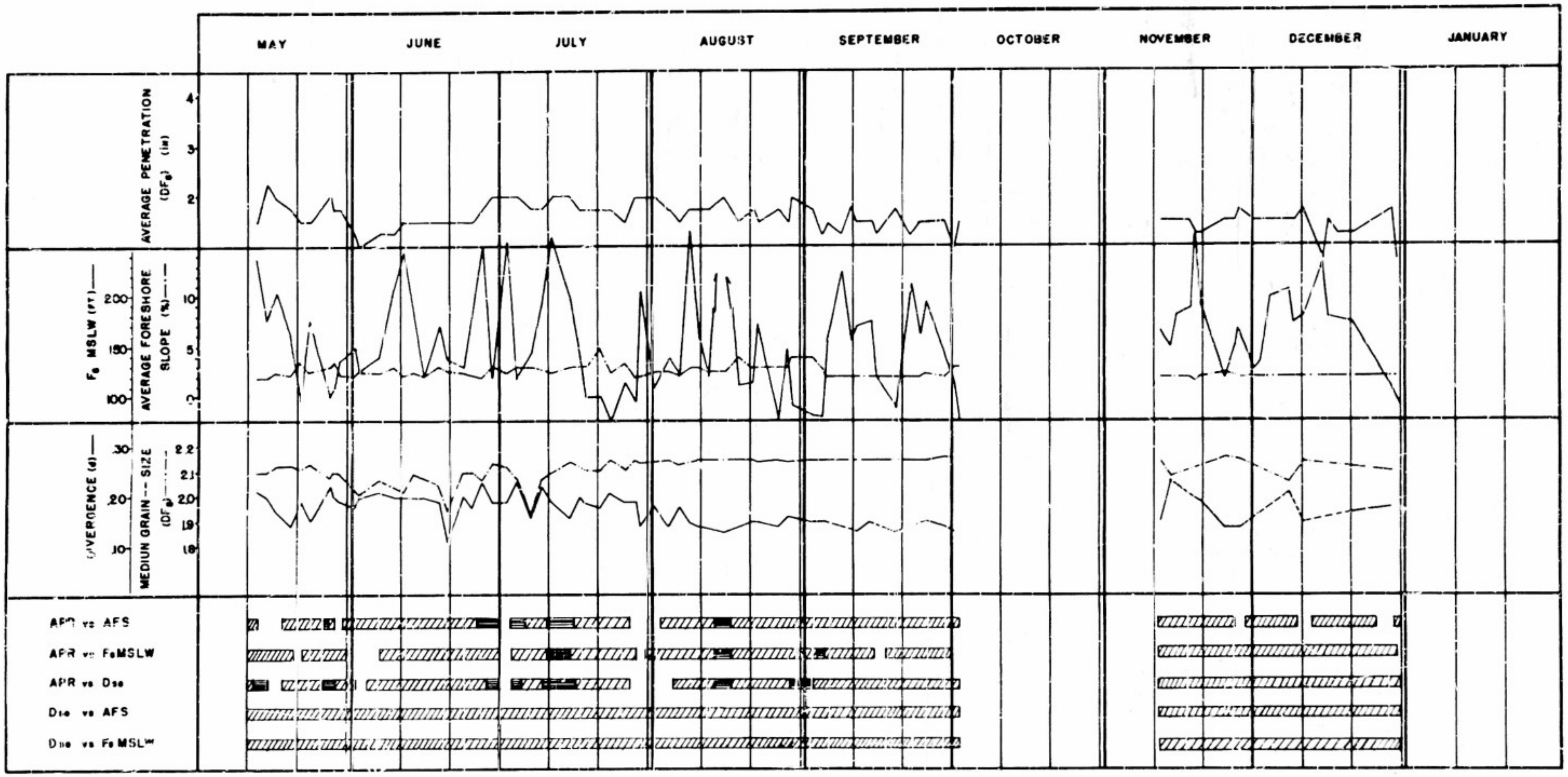


FIGURE 17

TIME CHARTS AND CORRELATION GRAPHS

BEACH 16

APPENDIX B

FIELD, LABORATORY AND ANALYSIS PROCEDURES

FIELD PROCEDURES

The data discussed and presented in this report was obtained by beach observers on a number of selected test beaches located along both the Atlantic and Pacific coasts of the United States.

Observers were employed at each beach to obtain the necessary data at frequencies ranging from once to four times weekly. Equipment was furnished by Cornell University. Observations and samples were forwarded regularly to Cornell for analysis.

The various methods of collecting data on the test beaches is described briefly in the following pages.

Time of Observations

The date and time of observation was recorded for each beach. Efforts were made to obtain observations at or near low tide levels.

Beach Profile

At each site, a reference point, consisting of a six-foot vertically sunk pipe, was established. The elevation of this pipe was referenced to some permanent point further inland. A line of observations, perpendicular to the waterline, was established between the reference point and the waterline.

Along the line of observations, elevations were taken with a rod and level at intervals of ten, twenty or forty feet (and at slope changes) depending upon the width and topography of the beach.

These profiles were vertically related to the established reference points.

Penetrometer Profiles

At each regular profile station (intervals of 10, 20 or 40 feet) across the beach, a reading with a constant weight cone penetrometer* was recorded. The values tabulated were the average of three readings at each station.

Sand Samples

Sand samples were taken of the surface sands on each beach. Generally, a representative sample of each major beach zone was obtained, i.e., the backshore, drying foreshore and wetted foreshore.

All samples were placed in cans, sealed and returned to the laboratory for analysis.

Wave Data

Information concerning the estimated direction, height and frequency of the waves attacking the beach, as well as the

*See Technical Report Number 5 and Volume IV of this Report.

number of breaker lines and the number of offshore bars, was recorded at the time of observation. This information was recorded for reference only and was not used in subsequent analyses.

Miscellaneous Data

Information concerning cusps, scarps, bars, current ripples, turbidity and shell was noted wherever these features were observed.

Ground Photography

Several views of the beach were taken with a Kodak Tourist II camera at the time of each observation. These pictures served as a permanent record of the ground characteristics and aided in interpreting the observation notes.

LABORATORY AND ANALYSIS PROCEDURES

Laboratory and analysis procedures were essentially the same as those described in Appendix A, Volume I of this Report. In addition, time-variation charts, such as those illustrated by Figures 5 to 17, were plotted. A number of other plots were also made but proved of little value.

APPENDIX C

DISCUSSION OF WAVE TANK TESTS

GENERAL

Included in the scheme of the complete research program was a small subdivision relating to wave tank tests. It was the purpose of these tests to obtain, under controlled laboratory conditions, data concerning beach profiles and stability as influenced by sand characteristics, gravity wave characteristics, and initial beach slope.

The tests were conducted during the summer of 1953 at the wave basin operated through authority of the School of Civil Engineering, Cornell University, Ithaca, New York.

The tests were designed by Professor M. S. Priest of the School of Civil Engineering with the cooperation of the senior author. Professor Priest was responsible for the technical supervision of the test and prepared the test report. In both phases he had the technical assistance of Mr. A. Amein.

The test report is naturally quite detailed in nature. Consequently, it cannot be included in this report in its entirety. Instead, a condensation is presented. The condensation quotes the test report liberally. Such quotations are identified by quotation marks.

EXPERIMENTAL SET-UP

The tests were conducted in a large, rectangular wave basin, 10' wide by 46' long by 4' deep with a wave generator at one end. Further details are omitted in the interest of brevity.

"Surface gravity waves were generated on fresh water within the basin by means of a curved wave generator, hinged at the bottom of the basin and extending across the basin, in a direction normal to the sidewalls. The generator was activated by an electric motor, through a speed reducer and eccentric. To the rear of the generator, wave energy was dissipated in gravel, which was supported by a metal frame with wire mesh.

Wave height was controlled through adjustment of the eccentric, and wave frequency was controlled through the pulley arrangement between motor and speed reducer."

Four different sands were tested simultaneously. They were selected upon the basis of increasing median grain-size but similarity of gradation (except Sand II). Sands I and II were actual beach sands from New Jersey. Sand III was a commercial sand obtained from a West Virginia supplier. Sand IV was a Standard Ottawa Sand. The gradation of the sands is shown in Figure 18.

"The sands were placed in strips (parallel to the long side of the tank) having a width of 2 or 4 feet, depending upon the sand, and a thickness of approximately 5 inches. These strips were separated by galvanized metal strips which extended well above the beach surface. The sands rested upon burlap, which was underlain by local sand, gravel, and cinder blocks, in turn. For the smallest value of initial beach slope, the waves approached the beach over a ramp having a slope of 1/6"."

MEASUREMENTS TAKEN

The following measurements were taken:

1. Wave frequency (measurement of time for an arbitrary number of generator cycles).
2. Wave height (point gage with checks by an electrical recorder).
3. Initial beach slope (engineer's level, rod and steel tape).
4. Final beach slope (same technique).
5. Height and spacing of ripples (rule and straight edge).
6. Index of firmness (beach penetrometer* and metal sphere of 7.31 lbs. and 11.8" circumference - metal sphere placed upon the sand, allowed to rest for a moment without other support, and removed - diameter of the resulting impression measured).
7. Reference firmness (penetrometer and spher impression on room-dry sand compacted in a large box by hand pressure).
8. Angle of repose (of each dry sand).
9. Mechanical analyses of various sands during the progress of the tests.

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* See Technical Report Number 5, "Use of Penetration Devices on Beaches".

PROCEDURES

"In view of the limited time set aside for this study, it was necessary to restrict the study to normal wave incidence and beach surfaces that were initially as nearly plane as practicable.

To investigate the influence of sand characteristics, wave characteristics, and initial beach slope upon beach profiles and beach stability, it was decided to investigate the behaviour of four different sands, at four different initial beach slopes, under wave action at four different wave heights and four different wave frequencies. The four sands, which were tested simultaneously, were all at the same initial beach slope for any test run.

One test run was chosen as a reference or common run. That is, it was taken as one test run in each series of four. Hence, the total number of actual test runs was 10."

The pertinent quantities for each test run are shown in Table X.

"Prior to each test run, except the first, each sand was thoroughly stirred in order to destroy any segregation or stratification. Each sand beach was then brought to as nearly a plane surface, at the desired slope, as was practicable.

Fresh water was admitted into the basin until the water depth was slightly greater than 2 feet. This was done slowly, and, after valve closure, some time was allowed before starting the test run to allow water within the interstices of the beach material to approach a static condition.

The wave generator was then set in motion and, after at least an hour had elapsed, wave height and wave frequency were determined. After approximately 8 hours of continuous operation, the wave generator was stopped.

Shortly after the wave generator was stopped, drainage of the tank was initiated. Approximately 15 to 18 hours after drainage was initiated, beach profiles and firmness measurements were made.

Firmness measurements were made at three locations on each 'beach':

1. Just 'shoreward' of the limit of wave uprush
2. On the beach face
3. A short distance 'seaward' of the beach face."

Reference measurements of firmness and angle of repose were taken following each test run.

TABLE X

CHARACTERISTICS OF EACH TEST RUN

Test Run	1A	2A	3A	4A	0B	1B	2B	1C	2C	3C
Wave Height (ft.)	0.021	0.089	0.120	0.188	0.120	←----	------	------	---	--→
Wave Frequency (cps.)	←-----	-----→	1.101	←----→	0.870	0.764	0.566	1.101	←--	--→
Initial Beach Slope (%)	←-----	-----→	4	←-----	------	------	-----→	8	12	16
Wave* Length	←-----	-----→	4.16	←---→	not applicable			4.16	←--	--→
Wave* Steepness	0.005	0.021	0.029	0.045	not applicable			0.029	←--	--→

* Deep water

RESULTS OF WAVE TANK TESTS

The major results of the wave tank tests are summarized in Tables XI and XII.

While inspecting the tables, it is convenient to remember the following characteristics of the four test sands (See Figure 18):

Sand I - fine sand, semi-uniform gradation

Sand III - medium sand, semi-uniform gradation

Sand IV - coarse sand, semi-uniform gradation

Sand II - medium-coarse sand, better gradation.

It is pointed out that the tendencies shown in Table XI involve the interaction of sand and waves in an attempt to form a relatively stable profile that presumably is characteristic of the sand that is under wave attack. The last four tendencies are of particular interest. They all indicate that the finer sands are constantly involved in an interaction leading to lower and gentler profiles, while the coarser sands are involved in an effort leading to, or maintaining higher slopes. These tendencies are in direct support of the slope-grain-size correlations of both Volume I and this Volume to the effect that lower average foreshore slopes are associated with finer sands, etc.

The tendency toward ripple formation is in direct support of statements made in Volume I.

The tendency in Table XII for coarser sands to show the greatest spherical and cone penetration is in direct support of the data presented in Volumes I, II and IV.

Figures 19a to 19c show the variations in firmness indices that occured after changes in wave height, wave frequency and initial beach slope. The measurements plotted refer only to those taken on the "beach face". The data shows no apparent trends and is inconclusive in this respect. However, the dominant effect of grain-size on all cone penetrations is well shown. The grain-size does not seem to have as pronounced effect upon the spherical penetration. The spherical penetration appears less erratic than the cone penetration.

In addition to the results presented in Tables XI and XII, there were one or two other interesting results.

"The most pronounced effects of an <u>increase</u> in relative wave height or wave steepness were:

1. A 'seaward' shift and extension of features, the offshore bar system being subject to greater shift and extension than the terminal bar.
2. An increase in the extent of scour and deposition.

The most pronounced effects of a <u>decrease</u> in wave frequency were:

1. A 'seaward' extension of the region in which there was sand movement.
2. A strengthening of tendencies toward the development of offshore bars.
3. An increase in the extent of both scour and deposition."

The statements regarding scour and deposition are in direct support and in direct contradiction to statements made in Technical Report Number 3, Beach Series, Volume I, to the effect that waves of greater height* erode beaches while waves of lower frequency* build beaches. However, they at least confirm statements to the effect that changes in wave height and frequency have an effect on beach conditions and are accompanied by turbidity stains.

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* All other factors being equal, and pertaining to preceding heights and frequencies.

TABLE XI

SUMMARY OF WAVE TANK RESULTS CONCERNING CHANGES IN BEACH PROFILE

Tendency	Test Sand Showing: Greatest Tendency → Least Tendency				Remarks
Toward current ripple formation	I	III	II	IV	Never observed on Sand IV Most often, for greater length, and most rapidly, on Sand I
Multiple offshore bars	I	III	--	IV,II	Bars of greatest height above initial beach surfaces on Sand I
Net movement of sand <u>seaward</u> from initial beach slope	I	---	--	---	Tendency to move seaward decreased as initial slope decreased
Net movement of sand <u>shoreward</u> from initial beach slope	IV	III	--	II	At lower values of initial slope. Tendency to move seaward at higher values of initial slope.
Height of terminal bar above initial beach surface	IV	III	--	II,I	Terminal bar corresponds to the area of wave wash, i.e., a part of the foreshore or beach face.
Scarp development	I	III	II	IV	For greater values of initial slope this replaced tendency to develop terminal bars.

TABLE XII

SUMMARY OF WAVE TANK RESULTS CONCERNING CHANGES IN BEACH FIRMNESS

Tendency	Test Sand Showing: Greatest Tendency → Least Tendency				Remarks
Toward greatest spherical penetration (least firmness)	IV	III	II	I	For variations in response to other variables, see Figure 19.
Toward greatest cone penetration (least firmness)	IV	II	III	I	For variations in response to other variables, see Figure 19.

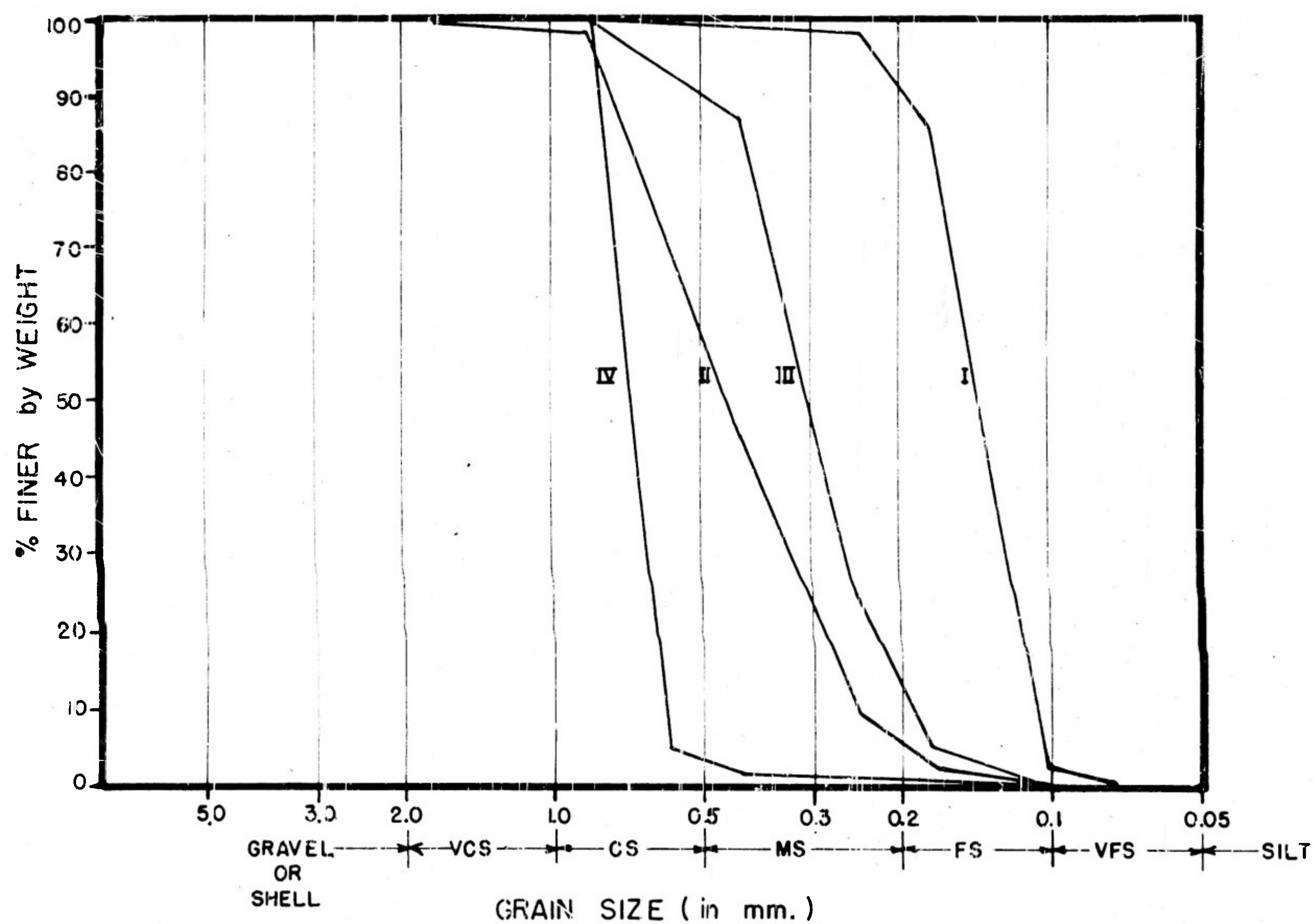

FIGURE 18 GRADATION OF SANDS USED IN WAVE TANK TESTS

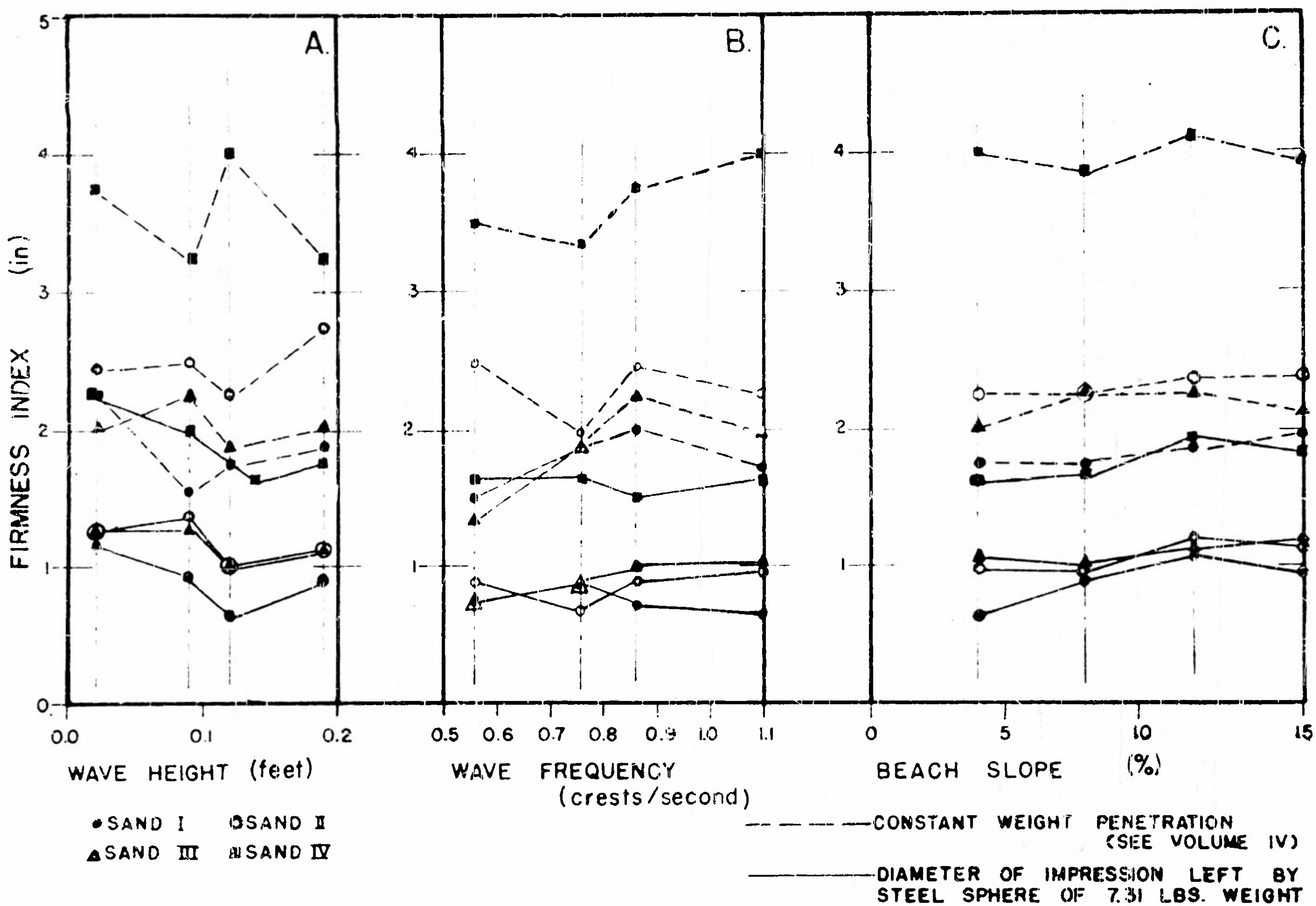

FIGURE 19 VARIATION IN FIRMNESS INDICES FOR VARIOUS WAVE HEIGHTS AND FREQUENCIES AND VARIOUS BEACH SLOPES.

CONCLUSIONS OF WAVE TANK TEST

Conclusions drawn from the wave tank tests are listed under the appropriate heading, in SECTION IV of this Volume.